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UTILIZATION OF SATURN/APOLLO CONTROL AND CHECKOUT SYSTEM FOR PRELAUNCH CHECKOUT AND LAUNCH OPERATIONS

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ABSTRACT

This paper presents a detailed discussion of the planning, development, application, and operational use of the Saturn/Apollo space vehicle control and checkout system for vehicle prelaunch checkout and launch operations at Kennedy Space Center/NASA.

The discussion reflects present vehicle prelaunch checkout and launch philosophy; describes the techniques and procedures currently used to conduct vehicle checkout and launch operations, and the operational capabilities of the control and checkout system; and reviews operational experience in specific applications of the system. Conclusions and recommendations are based on knowledge gained from all aspects of control and checkout.

The discussion does not include safety, quality assurance, and support operations, although these functions play a vital role in the overall conduct of Saturn/Apollo launch operations.

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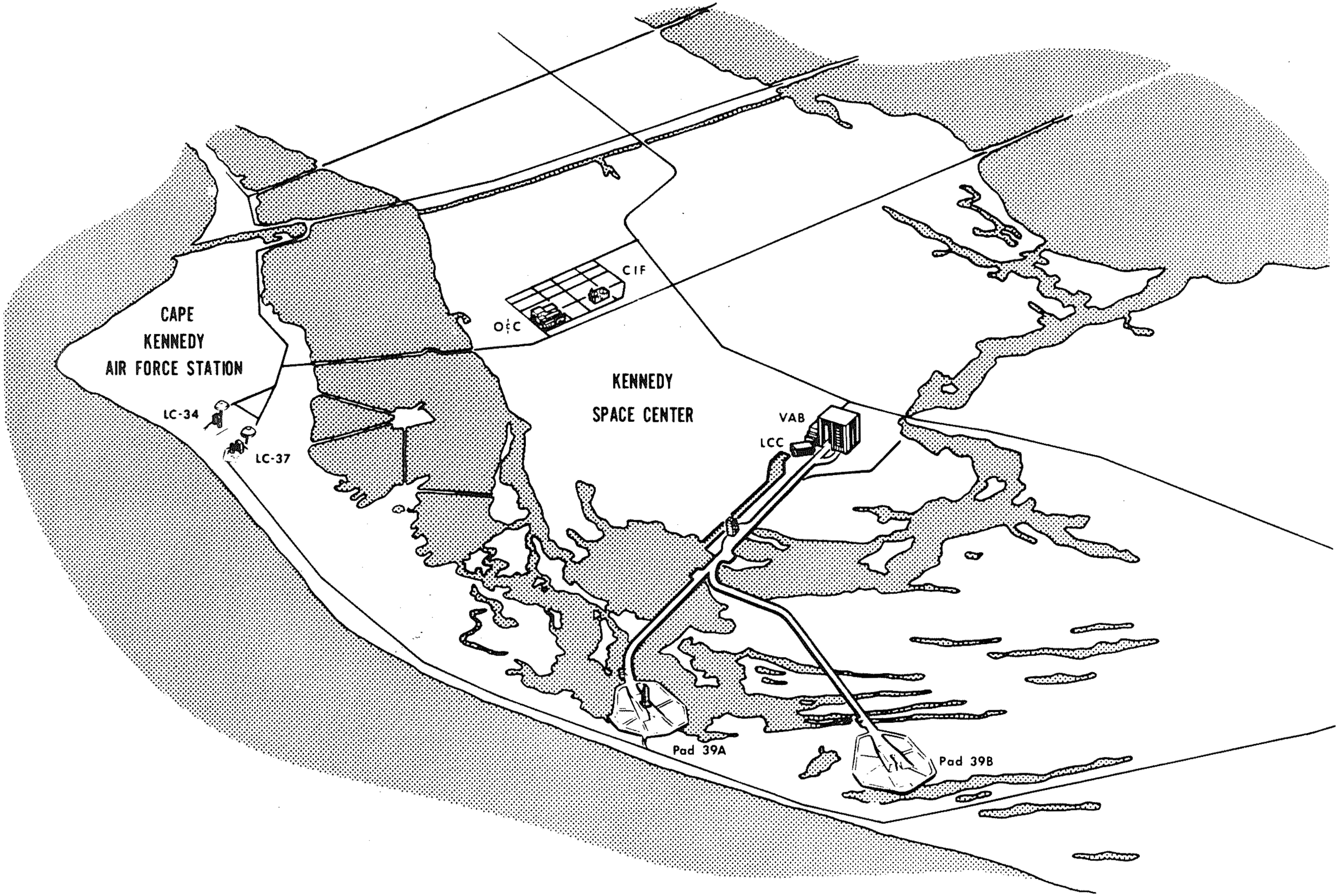

Figure A-1. Overall View of Saturn/Apollo Launch Operations Facilities

INTRODUCTION

Saturn Launch Vehicles

There are three launch vehicles associated with the Saturn/Apollo Program; the Saturn I, Saturn IB, and Saturn V. Saturn I launch operations demonstrated the validity of clustered rocket engines and aided in the development of the more powerful Saturn IB and Saturn V launch vehicles. The series of successful Saturn I launches qualified the guidance and control systems, demonstrated the structural integrity and physical compatibility of launch vehicle and spacecraft, and provided experience in applications of liquid oxygen and liquid hydrogen for rocket propulsion.

With the increased power of the Saturn IB second stage, the fully fueled Apollo spacecraft (command and service modules) will be placed in earth orbit. These orbital flights will be conducted to further demonstrate spacecraft systems performance and provide additional flight crew training.

The Saturn V launch vehicle will provide the thrust capability needed for the third and final phase of the Apollo Program, the actual lunar landing missions. The propulsion of the first two stages plus a short-period boost from the third stage will place the Apollo spacecraft in earth orbit. After coasting in orbit, the third stage engine will be restarted to accelerate the spacecraft along its lunar trajectory.

Saturn/Apollo Launch Complexes

Saturn/Apollo launch operations require extensive vehicle checkout and launch facilities. Figure A-1 presents an overview of launch operations facilities on Cape Kennedy Air Force Station and Kennedy Space Center. Launch Complexes 34 and 37 (Figure A-2) were previously used for Saturn I launch operations, and are presently being used for Saturn IB launch operations. For example, Launch Complex 34 (shown in the center of Figure A-2) is presently active in preparation for the first manned Saturn/Apollo launch (designated AS-205). Launch Complex 39, located on Kennedy Space Center (Figure A-1), is the site of Saturn V launch operations.

Each launch complex consists of a launch control center and vehicle assembly/ launch pad areas. Each launch pad requires a launcher, umbilical tower, flame deflector, service structure, and facilities to house control and checkout equipment. Assembly, checkout, and launch of the total Saturn IB vehicle configuration at Launch Complex 34 or 37 is accomplished by facilities permanently installed in the launch pad area. At Launch Complex 39, however, assembly and integrated testing of the Saturn V vehicle configuration is accomplished by facilities remote from the launch pad area. The launcher, its integral launch umbilical tower, and the control and checkout equipment are combined in a transportable unit commonly referred to as a mobile launcher. One of the mobile launchers is first moved into a high bay of the vehicle assembly building (Figure A-3) where access and handling equipment is provided for assembling the four stages of the Saturn V launch vehicle and the Apollo spacecraft. Visible in the center foreground in Figure A-3 is the launch control center. The launch control center has a firing room for each high-bay assembly area, and houses the operational personnel and the control and checkout equipment. After thorough space vehicle integrated tests have verified that the vehicle is ready for launch, a huge tractor device called a transporter transfers the mobile launcher and the space vehicle (Figure A-4) to one of the two available launch pads (Figure A-5). Then the transporter transfers the mobile service structure to the pad in preparation for final vehicle checkout prior to launch. The mobile concept of operation affords a considerably higher launch rate capability for a given pad facility. Equally important to the operations is the protection from the elements during assembly and checkout of the vehicle inside the vehicle assembly building.

There are two other facilities, located in the Kennedy Space Center industrial area, that are employed in prelaunch checkout. These are the operation and checkout building (Figure A-6), used for checkout of the Apollo spacecraft prior to mating to the launch vehicle; and the Central Instrumentation Facility (Figure A-7), the focal point for telemetry support of major prelaunch tests and launch.

Saturn/Apollo Control and Checkout Systems

Saturn/Apollo control and checkout systems, developed concurrent with the evolution of the three configurations of Saturn launch vehicle, were designed to meet the Saturn/Apollo vehicle performance and reliability goals. The Saturn IB and Saturn V control and checkout systems are basically the same, and each system features redundancy, repairability, and a reliable control system. Design has evolved from demonstrated advanced techniques which, in a very real sense, are the result of experience gained from actual checkout and launch operations. Information and data fed back to design personnel assisted them in incorporating the latest operational (user) requirements into the hardware.

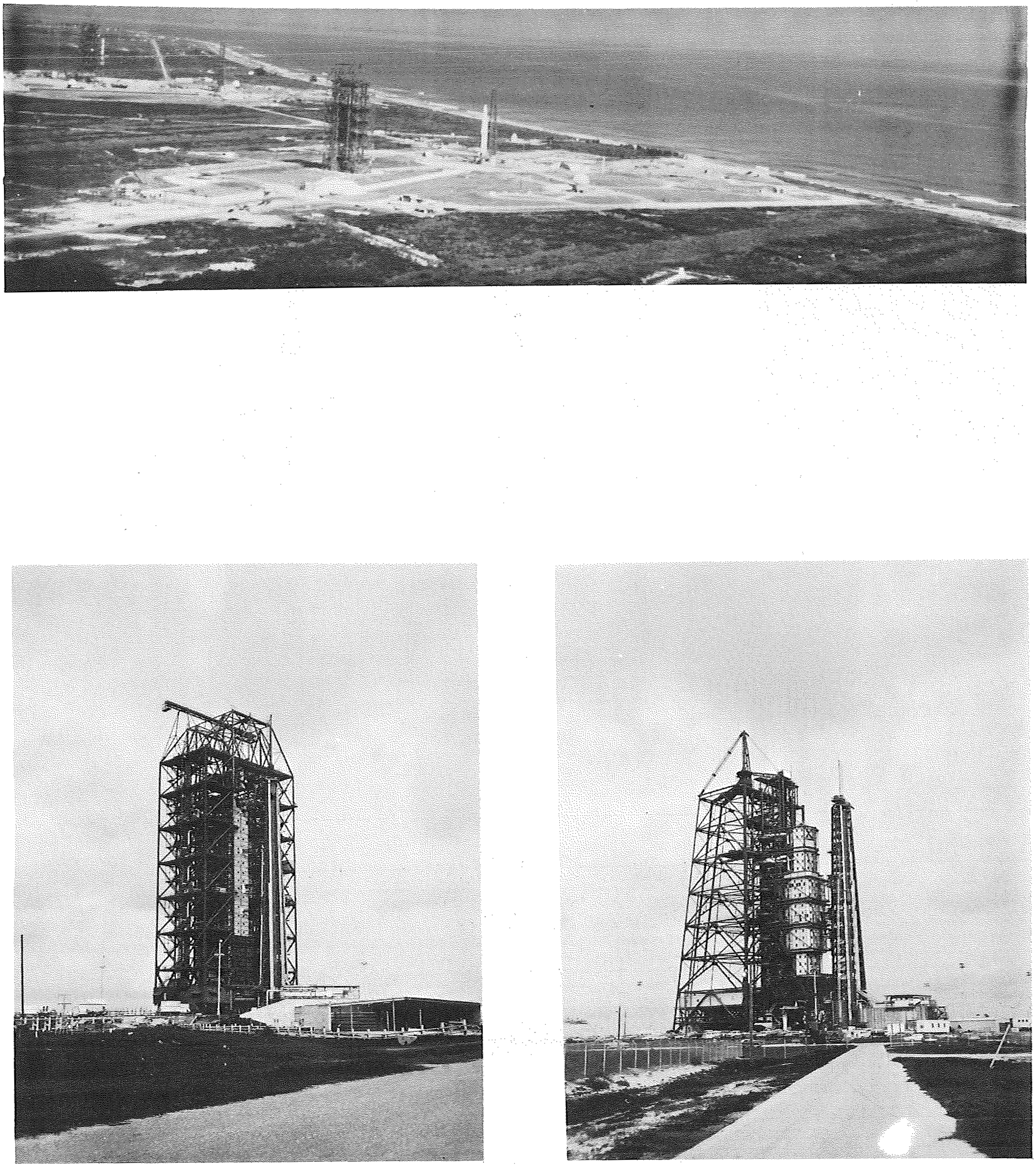

Figure A-2. Launch Complexes 34 and 37, Cape Kennedy Air Force Station

Figure A-3. Vehicle Assembly Building and Launch Control Center, Launch Complex 39, Kennedy Space Center

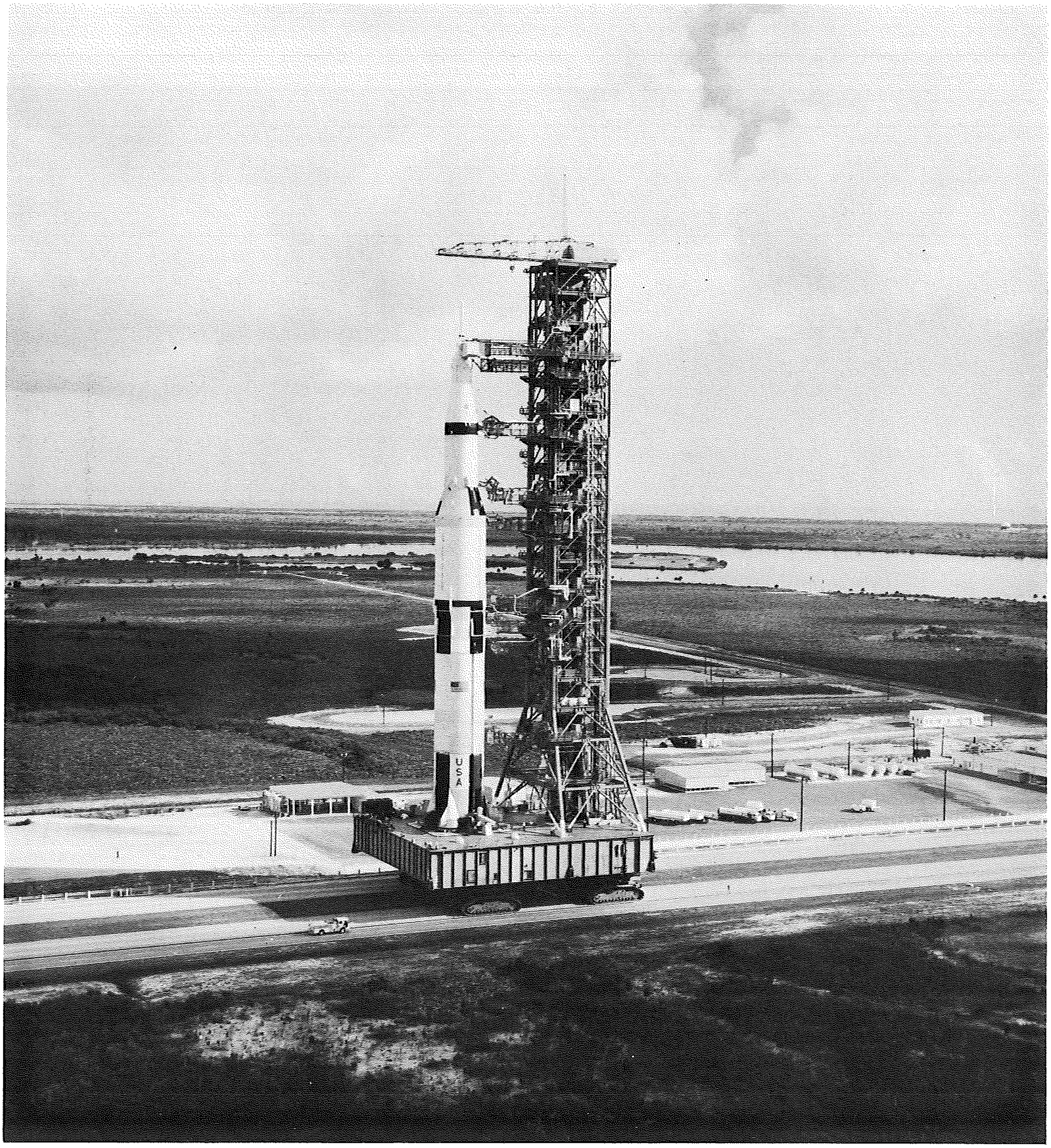

Figure A-4. Transfer of Saturn V/Apollo Space Vehicle Via Transporter

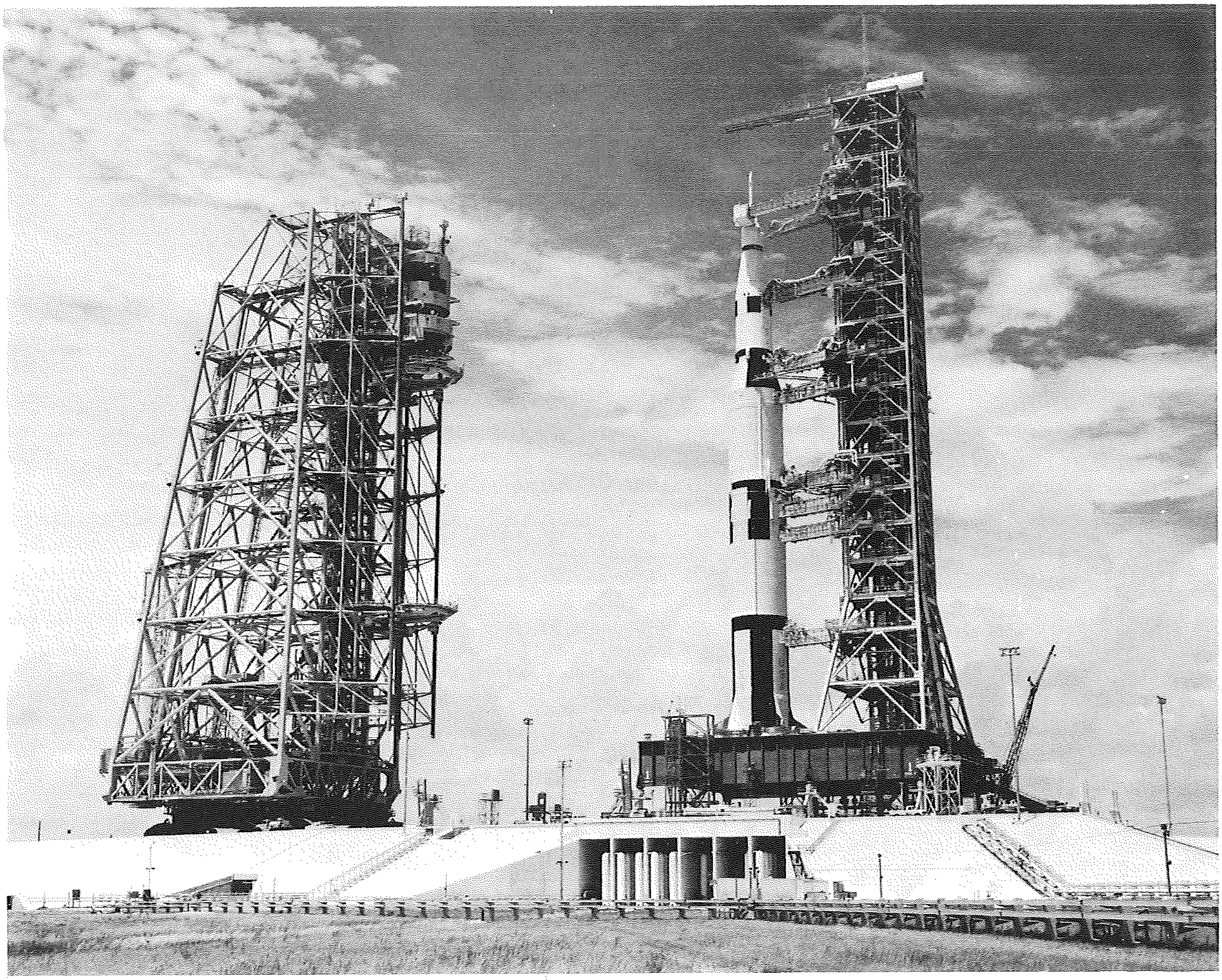

Figure A-5. Launch Pad, Launch Complex 39

Figure A-6. Operation and Checkout Building

Figure A-7. Central Instrumentation Facility

SECTION I
SATURN/APOLLO VEHICLE CHECKOUT AND LAUNCH PHILOSOPHY

Saturn/Apollo launch vehicle checkout and launch philosophy has evolved from a decade of experience in checkout and launch operations on the Redstone, Mercury-Redstone, Juno, experimental and tactical Jupiters, Pershing, Atlas-Centaur, Saturn I, and Saturn IB vehicles. A large percentage of the personnel who conducted these earlier rocket launches are still active in key positions of technical management, planning, and performance of launch operations at the Kennedy Space Center.

A. OBJECTIVE

The objective of space vehicle checkout at the launch site is to provide minimum testing to assure optimum flight readiness. This is accomplished by a building-block technique, starting at the subsystem level and progressing through systems, vehicle stages, and integrated vehicle testing. The Saturn/Apollo systems are still in the research and development phase and, therefore, research and development type testing is employed; that is, a relatively large number of system parameters are monitored compared, for example, to an operational vehicle or weapons system.

B. PLANNING

Planning and procedures are based on test requirements, specifications, and criteria furnished by the design agency (Marshall Space Flight Center), and tests and procedures updated from proven techniques and experience gained through launch operations activity. The space vehicle checkout plan has three phases:

1. Complex Activation

This phase involves validation of the space vehicle control and checkout system, umbilical disconnects, and fueling system as prerequisites to actual vehicle checkout.

2. Vehicle Checkout and Launch

This phase involves complete checkout of the assembled vehicle at the launch site, including utilization of preplanned actions when non-nominal situations occur during prelaunch checkout and launch countdown.

3. Complex Refurbishment

This phase involves refurbishment of the launch pad area to repair and/or replace equipment damaged during launch of the space vehicle.

C. NASA/CONTRACTOR ROLE IN LAUNCH OPERATIONS

In general, NASA manages and conducts launch operations using a launch team comprised of NASA and stage contractor personnel. Contractors that manufacture stages of the launch vehicle also have contracts with Kennedy Space Center for checkout of their respective stages. The contractors perform their tasks in accordance with approved design, launch operations plans, and checkout procedures.

1. System Test Engineer

The system test engineer performs the following functions:

a. Prepares and performs the detailed operational procedures.
b. Participates in scheduling of operations.
c. Resolves operational problems, and records operations and failures.
d. Participates in launch readiness reviews.
e. Performs test evaluations and postflight quick-look evaluation of vehicle systems.
f. Provides the design engineer with recommended changes when design deficiencies are noted. A formal change request format is used for this purpose.

2. Design Engineer

The design engineer maintains liaison between launch operations and the design agency in support of the following:

a. Verifies and controls changes to both the vehicle and the checkout system.
b. Furnishes the test specifications and criteria for each system.
c. Concurs with launch operations plans and procedures.
d. Provides recurrent control of component failures.
e. Performs postflight evaluation of vehicle systems.

Each of the contractors and the design agency have design engineering representatives assigned to Kennedy Space Center.

D. MISSION RULES

Mission rules are developed to provide guidance to the launch team organization by specifying preplanned decisions designed to minimize real-time rationalization when non-nominal situations occur during prelaunch checkout and launch countdown. When required, tests are performed at the Saturn Development Facility in Huntsville or at the launch site to verify the rationale used in the development of mission rules. Mission rules are prepared for each Saturn/Apollo IB and V mission. They apply to all operational activities and events in the countdown and launch of the space vehicle.

E. CONFIGURATION CONTROL

Detailed procedures and methods are implemented to control software and hardware changes to the Saturn launch vehicle systems and associated control and checkout systems. This configuration control procedure is based on NASA Specification NPC500-1.

1. Basic Policy

Basic policy discourages configuration changes. However, when required they can be initiated by both the designer and the test engineer. In addition, the test engineer can make an emergency change under the following conditions: the prevention of serious injury to personnel or serious damage to equipment, the prevention of a shutdown in launch vehicle operations, or the completion of a scheduled test, which would seriously impair Launch Vehicle Operations' ability to comply with the program commitment. All changes made after the space vehicle flight readiness test are strenuously controlled.

2. Change Request Route

The official change request route is through the Development Center at Marshall Space Flight Center and Program Offices at Kennedy Space Center. These program offices review requested changes to determine impact on schedules, costs, and contracts. During this review period the test and design engineers exchange technical information regarding the change request and aid the respective program offices as required. An expedite system exists to handle urgent changes.

3. Hardware Changes

Approved hardware changes are delivered to the launch site in mod-kit form. The mod-kit contains the following: parts, mod-kit instruction sheets, mod-kit parts lists, redline schematic, engineering orders, installation notice cards, and keypunch fact cards used to generate the correct wire list of the affected patch panel. In addition, the cards are used as input data to the Flexible Automatic Circuit Tester equipment which performs an automatic megger and continuity test of the entire patch panel. The test engineer reviews the mod-kit to ensure a total functional change and coordinates with the design liaison engineer regarding any discrepancies. Upon installation of the mod-kit, the test engineer updates all existing schematics that have been affected.

4. Software Changes

Approved software changes are transmitted to Kennedy Space Center on magnetic tapes or punched cards. Changes include: listings and flow diagrams, validation summary report, program trouble report (if applicable), program release notice, and program operating instructions. All changes are validated at the Saturn Development Facility or via special controlled tests at Kennedy Space Center prior to use.

F. TEST FLEXIBILITY

Testing flexibility is one of the important features designed into the control and checkout system of Saturn/Apollo launch vehicles.

1. Test Points

A large number of test points are available for use in isolating the causes of a malfunction. When conditions permit, these points are sometimes used to bypass a malfunctioning-circuit through the use of fused jumpers to allow completion of a test. The malfunction-circuit is then corrected and revalidated. A large number of displays consisting of indicating lamps, meters, recorders, and a computer-driven cathode ray tube display provide the system test engineer with redundant monitoring information for real-time test evaluation of the system.

2. Basic Modes of Operation

a. The manual mode is used primarily for emergency operations, or when the computer control techniques are not possible or have not yet been implemented.
b. The semiautomatic mode allows limited computer control operations.
c. The automatic mode allows complete computer control with manual intervention when required to downgrade the test to a semiautomatic or manual operation.

3. Circuit Interlocks

Circuit interlocks for personnel and equipment safety prevent testing beyond certain critical limits when a system has malfunctioned and response time does not allow safe intervention.

4. Redundancy

Redundancy of systems or alternate modes of operation decrease the mean-time between significant failure and repairability, thereby increasing the probability of meeting launch window requirements.

G. AUTOMATION

The complexity of launch vehicle systems required that the control and checkout system employ digital computers to reduce the time needed for launch vehicle checkout.

1. Automation Plan

To govern the progression of computer programs, an automation plan was implemented. This plan defines goals and objectives. The criteria governs the progression from vehicle to vehicle, establishes a base for updating programs from vehicle to vehicle, identifies and projects schedules for test programs, defines technical activity responsibilities and tasks necessary to implement the plan, identifies and defines documentation, and establishes the plan itself.

2. Objectives

The primary objective of the automation plan is to achieve an optimum level of automation for launch vehicle checkout within the resource constraints. Optimum automation considers maximum reliability, minimum test schedule time, operational manpower, and special equipment required. Test programs are developed for the tests selected for automation based on analysis of the trade-off factors involved. These programs are debugged and verified at the Marshall Space Flight Center Saturn Development Facility (Saturn "bread board") prior to delivery to Kennedy Space Center. The Saturn Development Facility simulates the entire launch vehicle and the control and checkout system. The "bread board" provides a very effective means for verifying systems performance and hardware/software compatibility.

3. Criteria for Selection

Analysis and priority criteria are used to select the tests that are proposed for automation (Figure 1-1).

a. Analysis criteria considers whether a proposed test is mandatory and involves critical timing and excessive manual checkout time, or no other capability exists.
b. Feasibility to automate considers the capability of the existing computer system, hardware, interface equipment, software modifications to the existing computer, and additional support facilities required.
c. Reduction of vehicle checkout time considers the capability to reduce total vehicle processing time, and to meet tight window schedules, or increase the time to take corrective action in the event of malfunction.
d. Software development and validation costs consider programming and programming support, facilities support (including the Saturn Development Facility), interface equipment modifications, computer hardware, and/or operating system program configuration.

Additional checkout benefits include time saved controlling tests or evaluating test results, and increased reliability because of efficient coordination of test operations and reduction in human error.

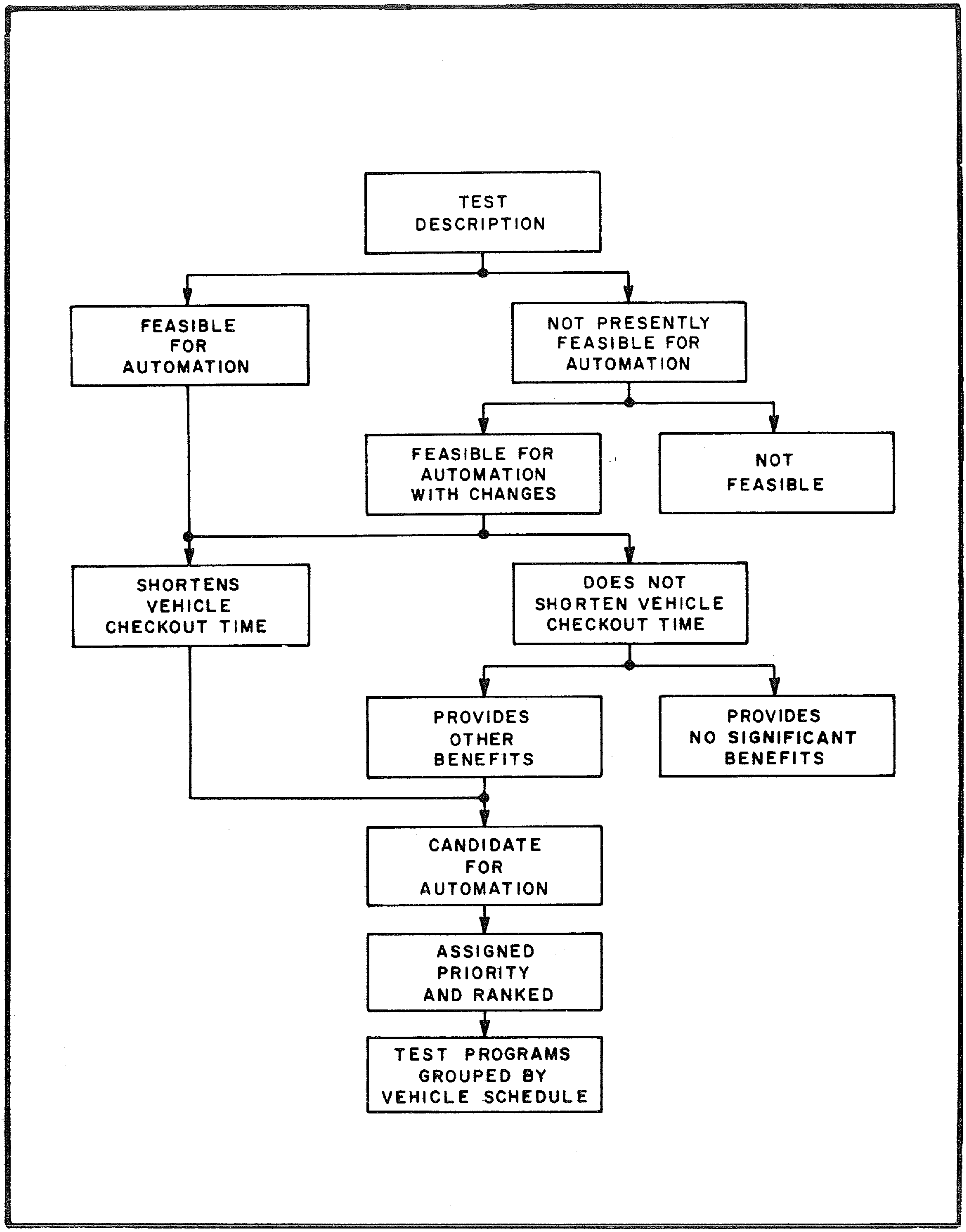

Figure 1-1. Automation Analysis Flow

4. Priority Criteria

The priority criteria is considered because a limited number of test programs can be debugged and validated in a given time period. Two general priority classes are considered:

a. Tests selected for automation to reduce vehicle checkout time and improve reliability, considering the amount of reduced checkout time, launch window constraints, or the number of repetitions of the tests.

b. Tests selected that, in themselves, do not reduce vehicle checkout time or significantly improve reliability, but may be automated if required as a part of the overall test.

5. Automation Baseline

The automation baseline identifies the computer programs committed to the current vehicle. Figure 1-2 reflects the relative time frame for the development of test program planning for these programs. The baseline is established at the time of the final vehicle automation commitment and assumes the existing status of the hardware and software configuration. Also, the baseline provides a starting point from which proposed automation will progress for future vehicles and a reference base to which proposed automation must relate.

6. Automation Projection

Automation projection on a master schedule (Figure 1-3) contains a list of candidate tests selected for automation (assigned grouping of candidates by vehicle), an estimate of the time required by the Saturn Development Facility for implementation of each candidate, and an indication of hardware and operating system changes required for implementation of each candidate. The projection will be updated for each vehicle.

H. TEST EVALUATION

The Saturn/Apollo space vehicle control and checkout system provides the required data display and recording needed for test operations. The Central Instrumentation Facility is the major facility for processing and distribution of telemetry data in real time to the Mission Control Center in Houston, to Marshall Space Flight Center in Huntsville, and for post-test data processing.

Maximum flight readiness is assured by a thorough evaluation of every test performed. Evaluation of each test, whether it is a component test or a major space vehicle overall test, consists of a complete analysis involving circuit timing, circuit parameter trends, correct system responses, and system tolerances. Continuous real-time evaluation is extensively employed by the control and checkout system computers and visual observations of all the display equipment. Major testing usually does not proceed until the evaluation of a previous test has been successfully completed.

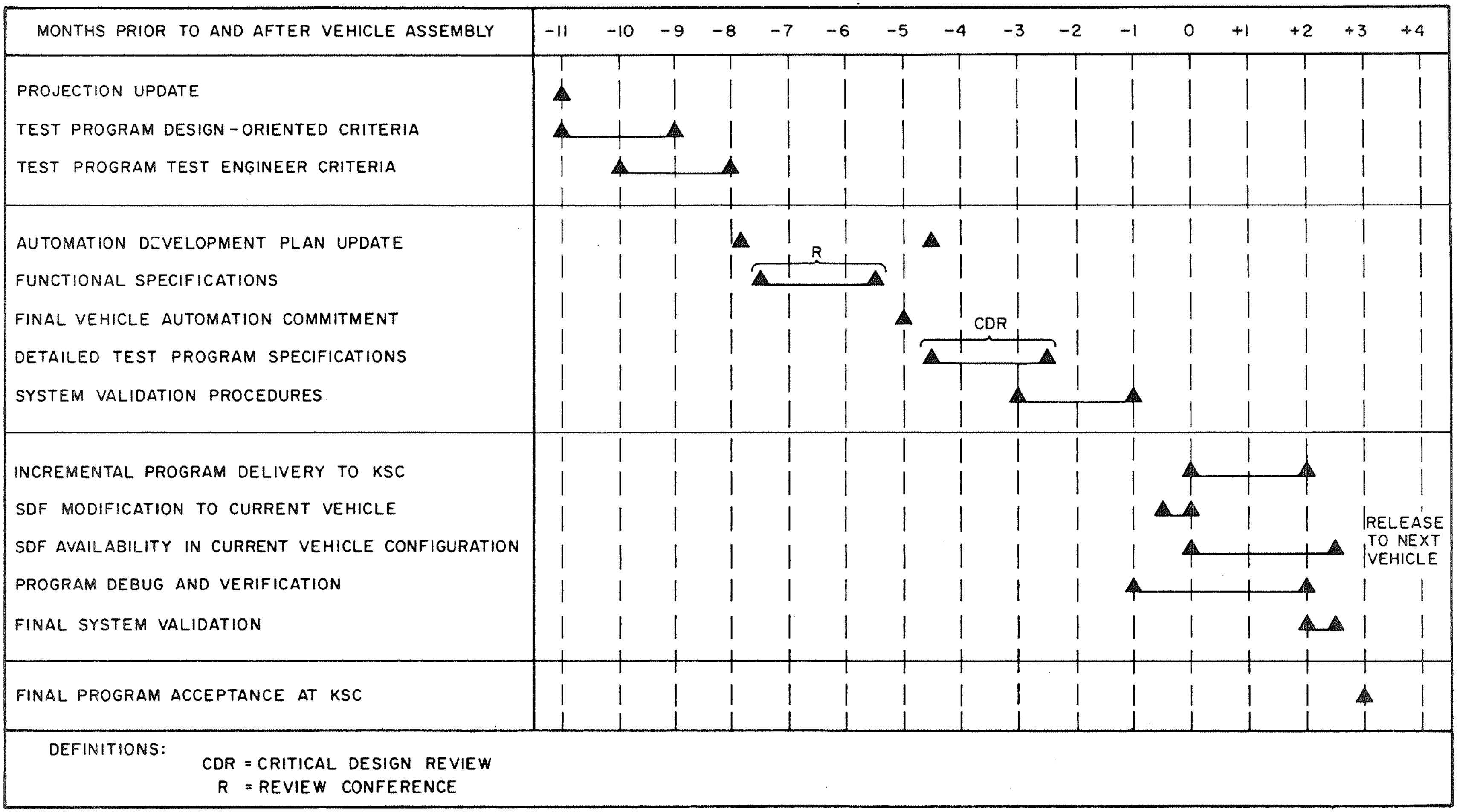

Figure 1-2. Typical Format for Test Program Planning

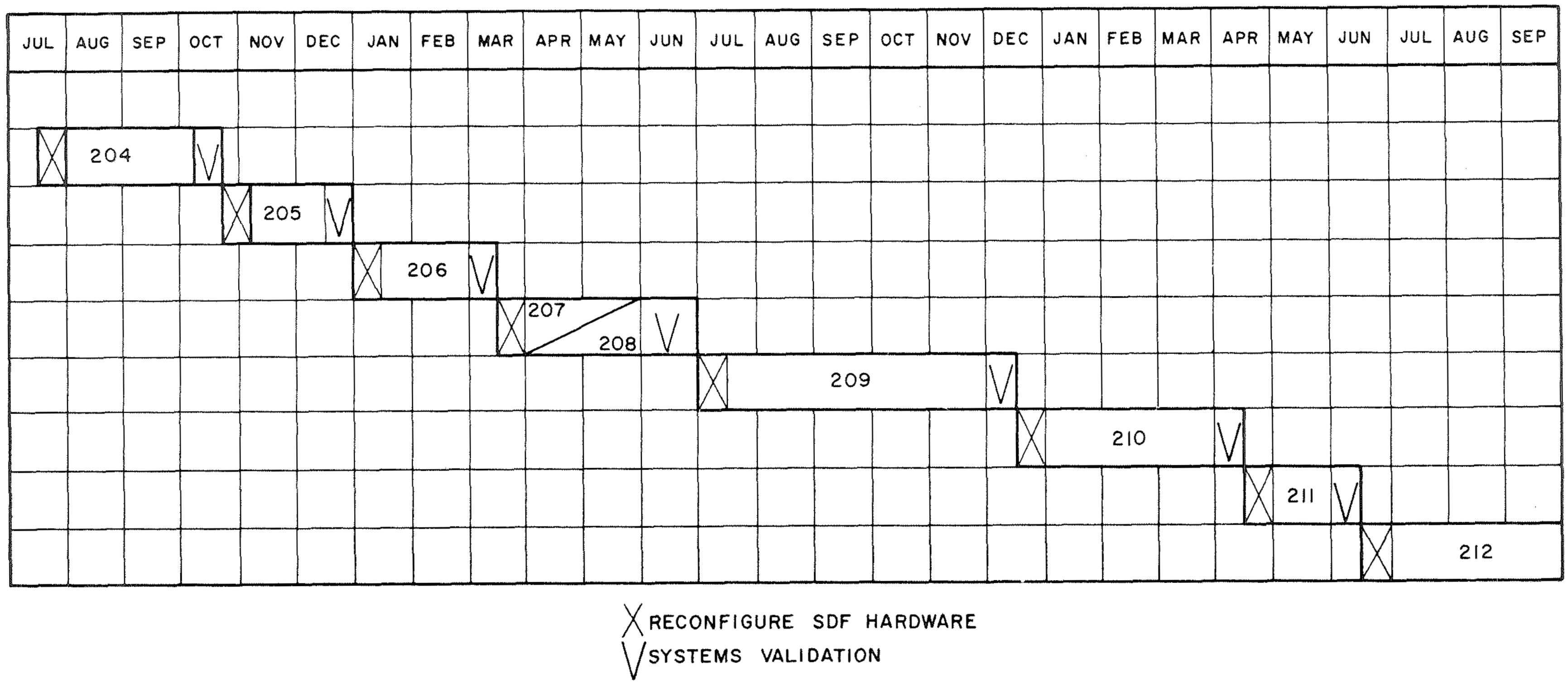

Figure 1-3. Typical Saturn IB Saturn Development Facility Master Schedule

SECTION II
PRELAUNCH AND LAUNCH CHECKOUT

A. PLANNING

Saturn/Apollo space vehicle prelaunch checkout and launch operations include planning, scheduling, procedure preparation, test operation, and test evaluation.

Prior to the arrival of a vehicle, launch operations requirements from the previous launch are updated to include any changes or additions to meet requirements for the current mission. Effective planning and scheduling of operations are based on realistic estimates of arrival of launch vehicle stages and spacecraft modules, and launch dates. The basic operational plan includes:

1. Ground System Qualification.
2. Stage and Spacecraft Premating Operations.
3. Space Vehicle Assembly.
4. Spacecraft/Launch Vehicle Coordination.
5. Stage and Space Vehicle Checkout.
6. Ordnance Installation.
7. Radioactive Materials and Hypergolics Handling and Storage.
8. Launch Countdown Operations.
9. Post-Launch Operations.
10. Refurbishment Procedures.

Vehicle transfer procedures are also included in the plan when operations apply to Saturn V/Apollo vehicle launch from Launch Complex 39.

B. PROCEDURES

A catalog of all test procedures to be performed is prepared by the test engineers at Kennedy Space Center. Each test procedure to be developed is described on a test catalog form, as shown in Figure 2-1. Information required on the test catalog form includes test title, test number, system identification, test objectives, test descriptions, equipment status, vehicle effectivity, test location, computer program identification, estimate of test time, test configuration, and support requirements. All of the test catalog forms combined provide a summary of all scheduled tests and are published for each vehicle. The test catalogs are submitted to the design engineer for review and concurrence.

The basic test procedure flow (Figure 2-2), is initiated in response to the test requirements from the design agency, or an operational requirement by Kennedy Space Center. Existing procedures, used in previous launch vehicle checkout, are used to the maximum extent possible by updating them to include new test requirements and related test specifications and criteria. Additional information in the test procedures include, but are not limited to, the following:

1. Pre-test requirements.
2. Test equipment.
3. Communications.
4. Operational sequence emergency procedures.

KSC OPERATIONS **APOLLO/SATURN TEST CATALOG**	PAGE 1 OF 2
1. TEST TITLE L/V SWITCH SELECTOR FUNCTIONAL TEST	2. KSC TEST NO. I-20003-SA4/12 3. STAGE, VEHICLE OR GSE SATURN IB

4. TEST OBJECTIVES

THE OBJECTIVE OF THIS TEST IS TO VERIFY PROPER OPERATION OF THE LAUNCH VEHICLE SWITCH SELECTORS.

5. TEST DESCRIPTION/EQUIPMENT STATUS

PART I: INTERFACE TEST (MANUAL): PANEL COMMANDS WILL BE ISSUED TO VERIFY STAGE SELECT, BIT VERIFY, RESET, INHIBIT, ALL ZEROS, AND ALL ONES (REGISTER TEST) CIRCUITRY.

PART II: INTERFACE TEST (AUTO): COMMANDS WILL BE ISSUED (AS IN PART I) BY PROGRAM NT02 TO VERIFY THE GROUND COMPUTER/ SWITCH SELECTOR INTERFACE. OPEN ADDRESS AND DUAL STAGE SELECT MALFUNCTIONS ARE INTRODUCED AND VERIFIED.

PART III: CHANNEL TEST: EACH SWITCH SELECTOR WILL BE SELECTED AND ALL OUTPUT CHANNELS ISSUED TO VERIFY STAGE AND CHANNEL ISOLATION. MULTIPLE OUTPUT MALFUNCTIONS ARE INTRODUCED AND VERIFIED. PROGRAM NA03.

(CONTINUE ON KSC FORM 23-192 IF REQUIRED)

6. PREPARED BY	8. NASA-KSC APPROVAL	10. APPROVAL DATE
7. ORGANIZATION	9. ORGANIZATION	11. VEHICLE EFFECTIVITY AS- 204 - 212

KSC FORM 23-191 (2/66)

Figure 2-1. Saturn IB/Apollo Test Catalog Format (Sheet 1 of 2)

APOLLO/SATURN TEST CATALOG (Continuation Sheet)			PAGE 2 OF 2
1. TEST TITLE LAUNCH VEHICLE SWITCH SELECTOR FUNCTIONAL TEST			2. KSC TEST NO. I-20003-SA4/12 11. VEHICLE EFFECTIVITY AS- 204 & SUBS.
12. WHERE TEST PERFORMED LC 34/37	13. COMPUTER/ACE PROG. IDENT. (IF APPLICABLE)		14. EST. TEST TIME
15. TEST CONFIGURATION MALFUNCTION SIMULATOR CONNECTED TO SWITCH SELECTOR			

16. SUPPORT REQUIREMENTS CHECKLIST *(Check appropriate boxes and add any additional)*

[X] GROUND POWER	[X] LCC MEASURING (LVO)	[ ] ETR/KSC RADAR
[X] S-IB OR S-IC STAGE PWR	[ ] LCC MEASURING (INS)	[ ] ETR COMMAND XMITTER
[ ] S-II STAGE POWER	[X] GSE MEASURING (LVO)	[ ] LOCAL COMMAND (C.L.)
[X] S-IVB STAGE POWER	[ ] GSE MEASURING (INS)	[ ] ALDS
[X] IU POWER	[ ] LCC DATA DISPLAY	[ ] LCC TM STA. (MONITOR)
[ ] LEM POWER	[ ] CIF DATA DISPLAY	[ ] LCC TM RECORDING
[ ] SM POWER	[X] DDAS	[ ] CIF TM STA. (MONITOR)
[ ] CM POWER	[ ] DDAS TAPE RECORDING	[ ] CIF TM RECORDING
[X] BACK-UP BATTERIES	[X] SERVICE STRUCTURE MEAS.	[ ] CIF COMPUTER
[ ] TIMING	[X] RCA-110A COMPUTERS	[ ] CIF DATA
[X] COUNTDOWN CLOCK	[ ] ACE	[ ] TM RECORDS
[ ] ETR SEQUENCER	[ ] L/V W-G ECS	[ ] REAL-TIME CIF COMPUT.
[ ] ETR COUNTDOWN CLOCK	[ ] CM W-G ECS	[ ] POST-TEST CIF COMPUT.
[ ] ETR S.R.O.	[ ] FACILITY ECS (GAS)	[ ] KSC TRACKING
[ ] ETR R.S.O.	[ ] H.P. GAS	[ ] RFI MONITORING
[ ] ETR PAD SAFETY	[ ] CCF	[ ] RF READOUTS (ETR)
[ ] KSC PAD SAFETY	[ ] FACILITY TV (OTV)	[ ] RF READOUTS (KSC)
[ ] SECURITY POLICE	[X] FACILITY COMM. (OIS)	[ ] WEATHER FORECAST
[ ] FIRE FIGHTING	[ ] FILM CAMERAS	[ ] MCC-C
[ ] MEDICAL	[ ] SEARCH LIGHTS	[ ] MCC-H
[ ]	[ ]	[ ] FOOD SERVICE
[ ]	[ ]	[ ]
[ ]	[ ]	[ ]
[ ]	[ ]	[ ]
[ ]	[ ]	[ ]

OTHERS:

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17. OTHER APPLICABLE REFERENCE DOCUMENTATION

Figure 2-1. Saturn IB/Apollo Test Catalog Format (Sheet 2 of 2)

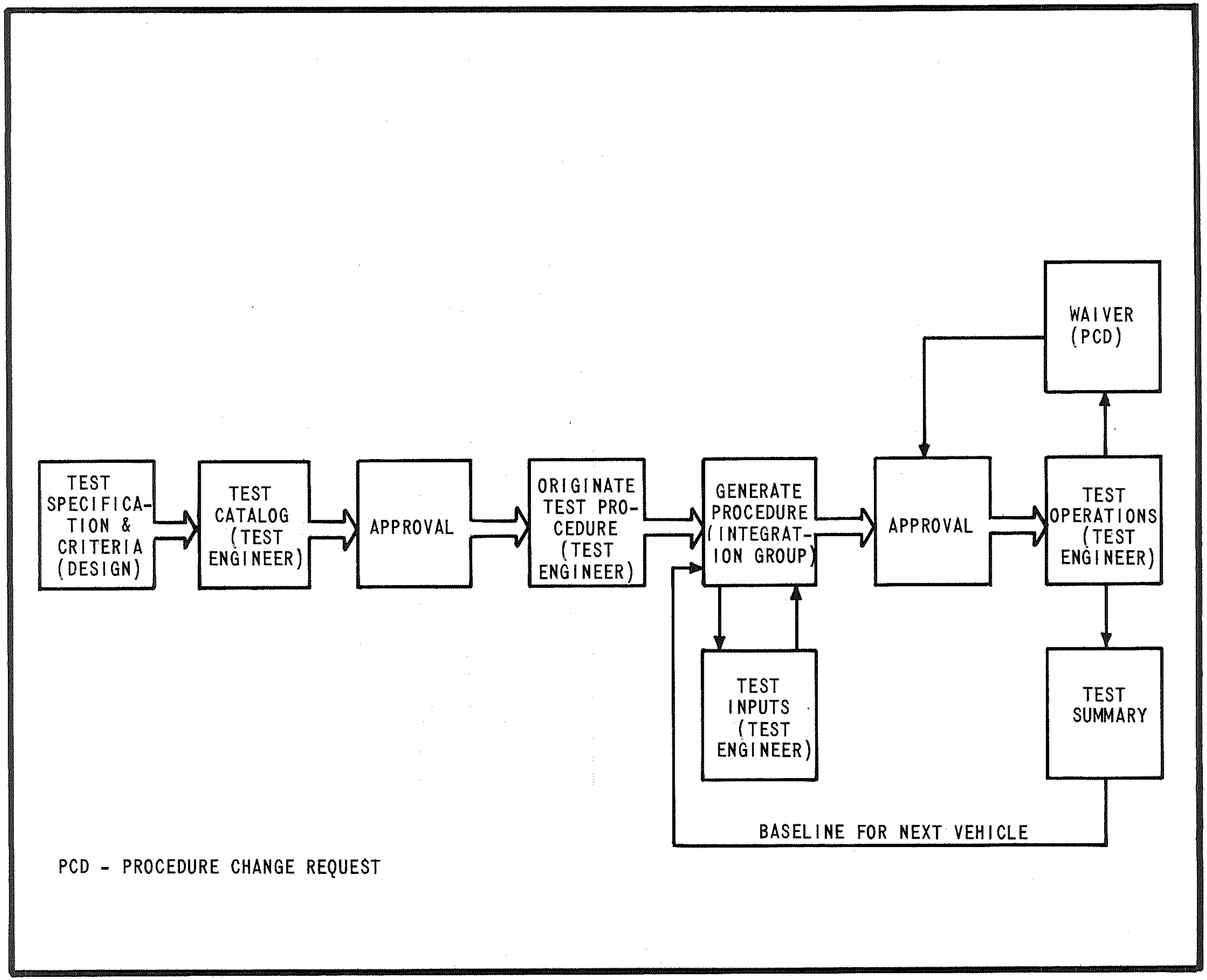

Figure 2-2. Test Procedure Flow

5. Data and summary sheets.
6. Post-test requirements.
7. List of reference documents.

Reference documents may include support check lists, validation and/or calibration procedures. The use of reference documents in preforming work must be approved in advance. Test procedures must include all actions necessary to place the system, stage, module, or vehicle into the configuration required for the test. The procedure is then distributed to all affected test engineers for review to resolve any conflicts or inconsistencies. All inputs are consolidated and released for use after proper approval.

During the test operations, all deviations must receive prior approval. After the successful conclusion of the test, a test summary is prepared. Any deviations noted during the operations are then fed back to update the test procedure for use the next time the procedure is run, or as a base line for the next vehicle.

An example of test procedures used to checkout the vehicle guidance system is shown in Figure 2-3. The procedure covers a time span of prearrival checks through post test evaluation. The prearrival procedures consist of calibration of all instruments and test equipment used at the launch site and laboratory, and receiving and inspection in the laboratory or in the vehicle if the items were shipped installed.

Laboratory checkout of the flight spares consists of verification of the launch vehicle data adapter, launch vehicle digital computer, and the combined launch vehicle data adapter and digital computer. Checkout of the flight items are normally accomplished at the launch site but are performed in the laboratory when required.

Tests performed at the launch site consist of a system functional test, including validation of the guidance interfaces with the control and checkout system, the vehicle measuring calibration, and all vehicle interfaces with the guidance system. These consists of the digital data acquisition system, the switch selector, the command system, and the control and stabilized platform systems.

In general, the launch vehicle guidance system procedures for launch and space vehicle overall tests are identical. In addition to these procedures, the guidance test engineers provide the necessary inputs to the launch and space vehicle integrated overall test and launch procedures. These inputs are usually milestones consisting of time of power-up and time-to-be-ready, status, and time critical operations. Each test procedure contains the necessary logging and post-test evaluation work that must be satisfactorily performed.

To produce an automated test procedure, using the Acceptance Test or Launch Language (ATOLL), requires a complete analysis of the proposed test and the initiation of a request for a computer program. The procedure flow is shown in Figure 2-4.

The system test engineer, on completion of the analysis, proposes the program requirements to the automation group. The automation group then prepares the

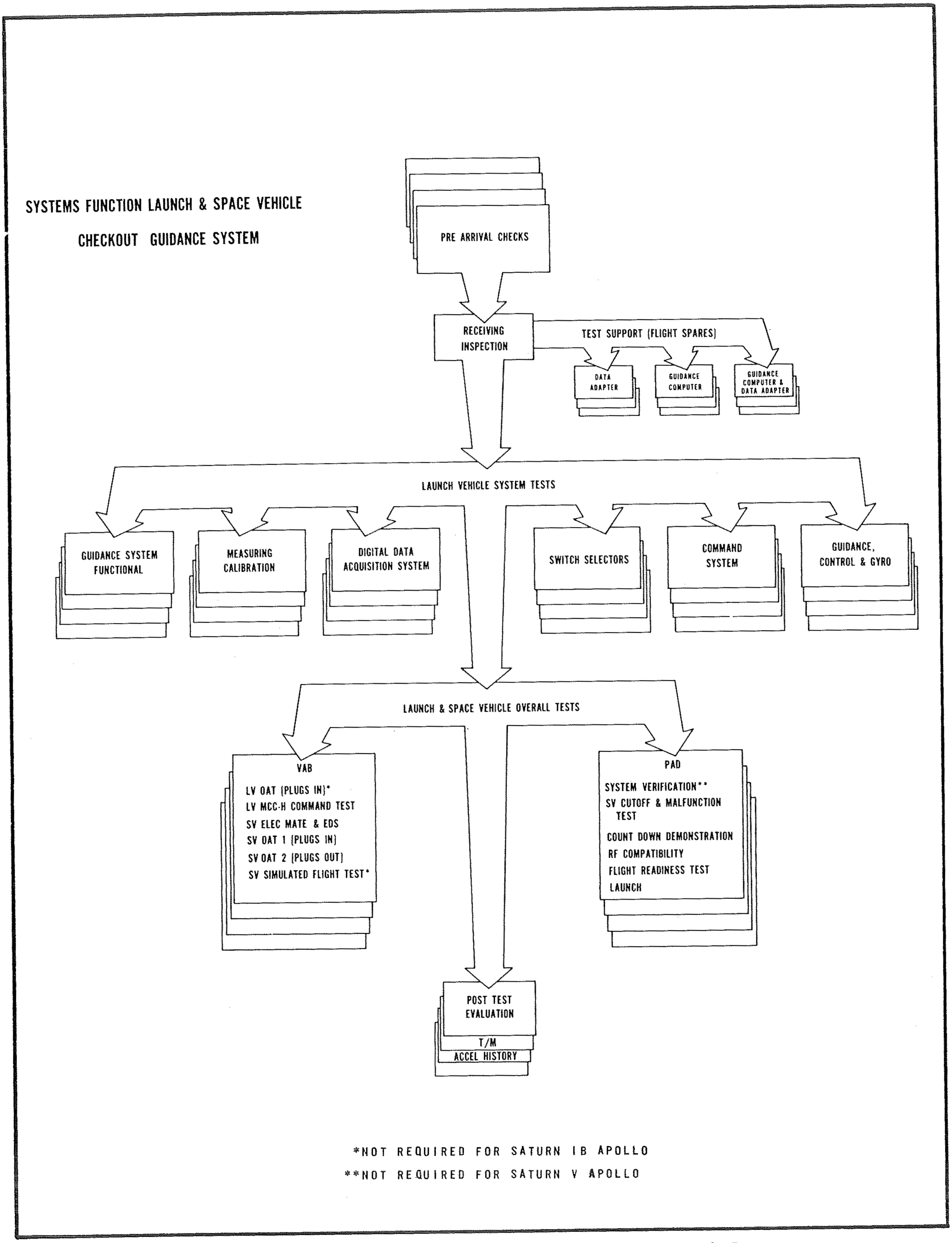

Figure 2-3. Typical Systems Function Launch and Space Vehicle Checkout Guidance System

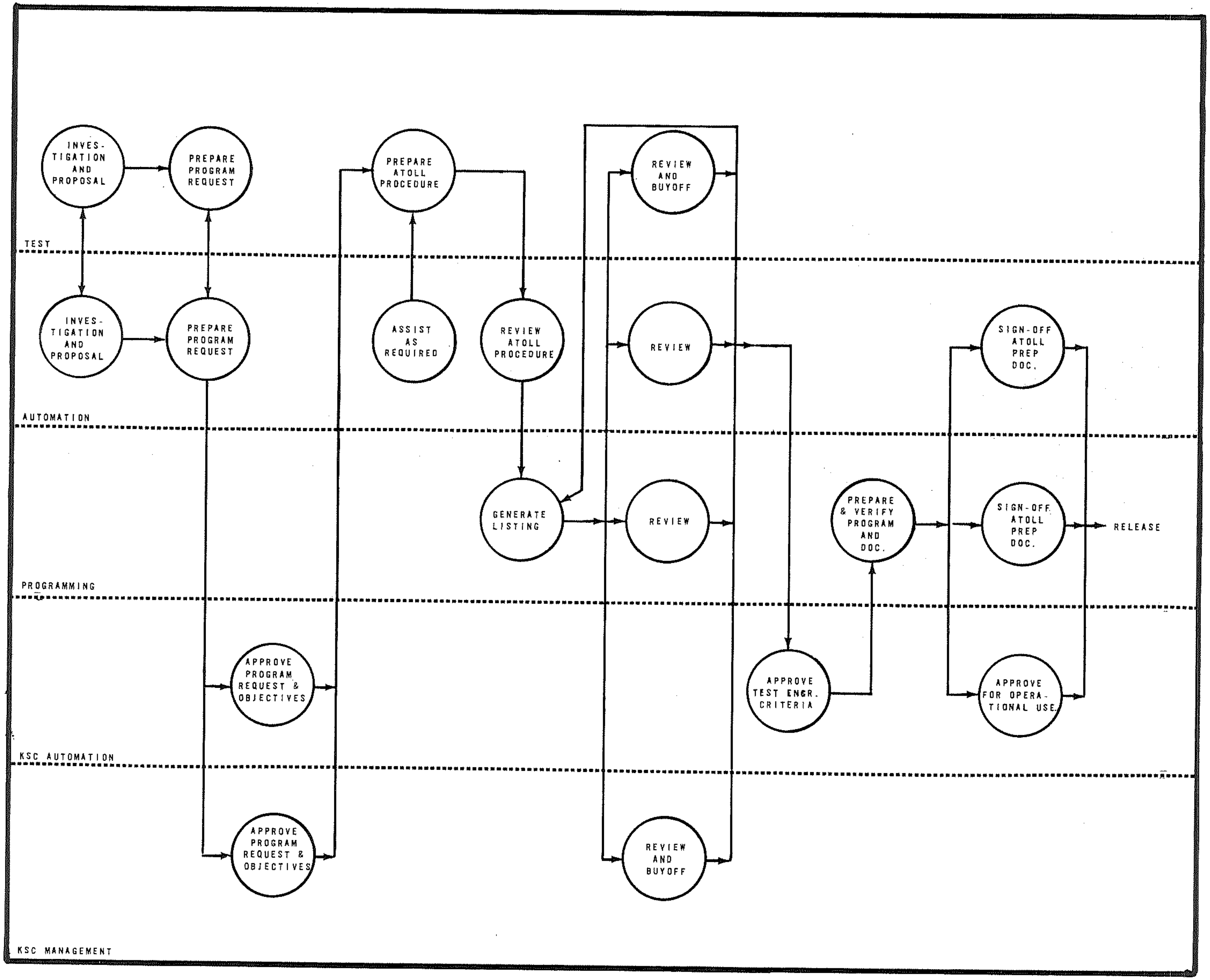

Figure 2-4. ATOLL-Automated Stage Test Procedure Flow

request, which is submitted for approval. If approved, the system test engineer then prepares the procedures using ATOLL, with the assistance of the automation group. The programmers then generate the ATOLL listing.

A review cycle by all groups involved confirms that there are no compiling errors. The system test engineer's criteria (listing) is approved as the program definition and is returned to the programmers who prepare the proper documentation, consisting of operating instructions, description of the program, and flow charts. In addition, the program is verified either at the Kennedy Space Center using a Saturn ground computer complex that is not being used for vehicle checkout, or it is sent to the Saturn Development Facility in Huntsville. The program is then officially bought off with final documentation, which includes the validation procedures. Prior to operational use of the program, a test procedure is prepared or updated as previously described.

C. SCHEDULING

A typical Saturn IB/Apollo space vehicle checkout and launch schedule is essentially broken into three parts; launch vehicle, spacecraft, and combined space vehicle checkout, as shown in Figure 2-5. Both launch vehicle checkout and spacecraft checkout are timed for completion at spacecraft electrical mate with the launch vehicle.

1. Launch Vehicle Checkout Functional Flow

The launch vehicle checkout is conducted in four phases (Figures 2-6 and 2-7):

a. Pad activity required prior to vehicle assembly.
b. Launch vehicle assembly and mechanical systems checks.
c. Subsystem and system testing, consisting of power-up, telemetry and RF checks, and propulsion and hydraulic checkout.
d. Launch vehicle integrated testing consisting of launch vehicle electrical mate, switch selector functional test, propulsion dispersion test, launch vehicle power transfer, individual guidance and control systems checks, combined guidance and control system checks, launch vehicle-Mission Control Center-Houston interface test, launch vehicle sequence malfunction test, launch vehicle full pressure test, and the environmental cooling system test. At this point the launch vehicle is ready for spacecraft electrical mate.

2. Spacecraft Checkout Functional Flow

A typical Saturn IB/Apollo spacecraft checkout functional flow (Figure 2-8) is conducted in two parts consisting of receiving and inspection and spacecraft checkout. These processes include the following equipment:

a. Launch escape system.
b. Service module and its associated reaction control system propulsion modules (quads).
c. Service module/lunar module adapter.
d. Command module.

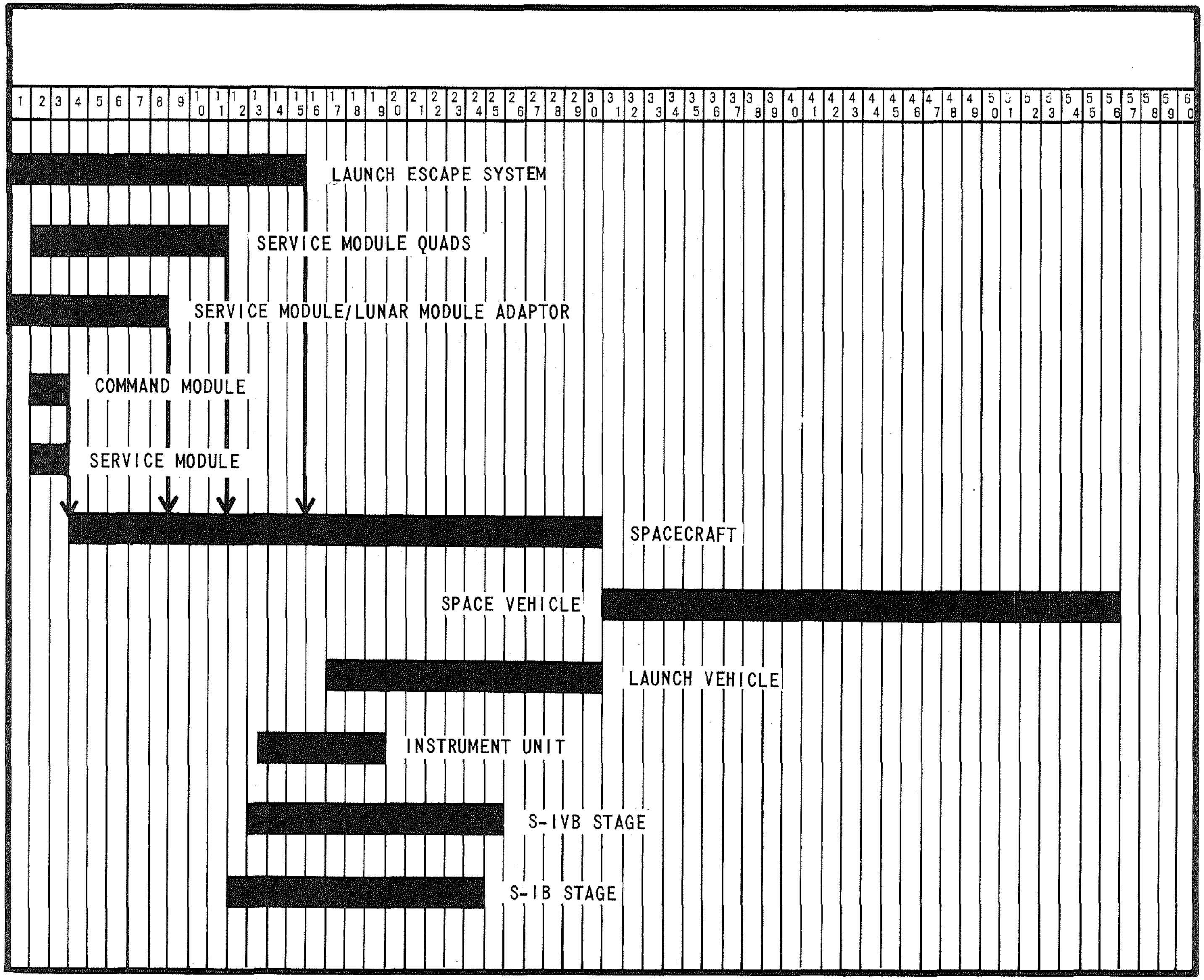

Figure 2-5. Typical Saturn IB/Apollo Space Vehicle Checkout and Launch Schedule

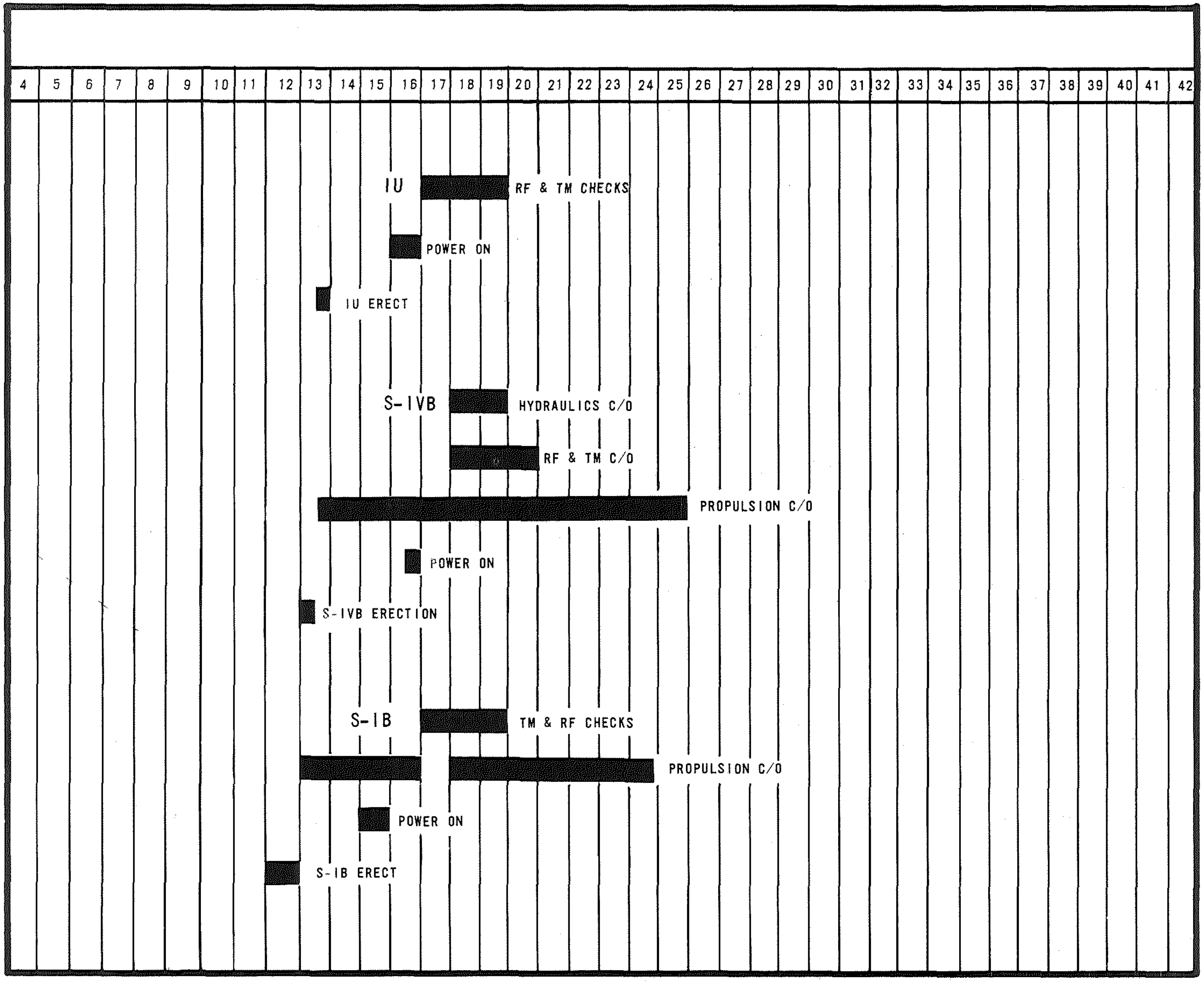

Figure 2-6. Typical Saturn IB/Apollo Stage Time-Based Functional Flow

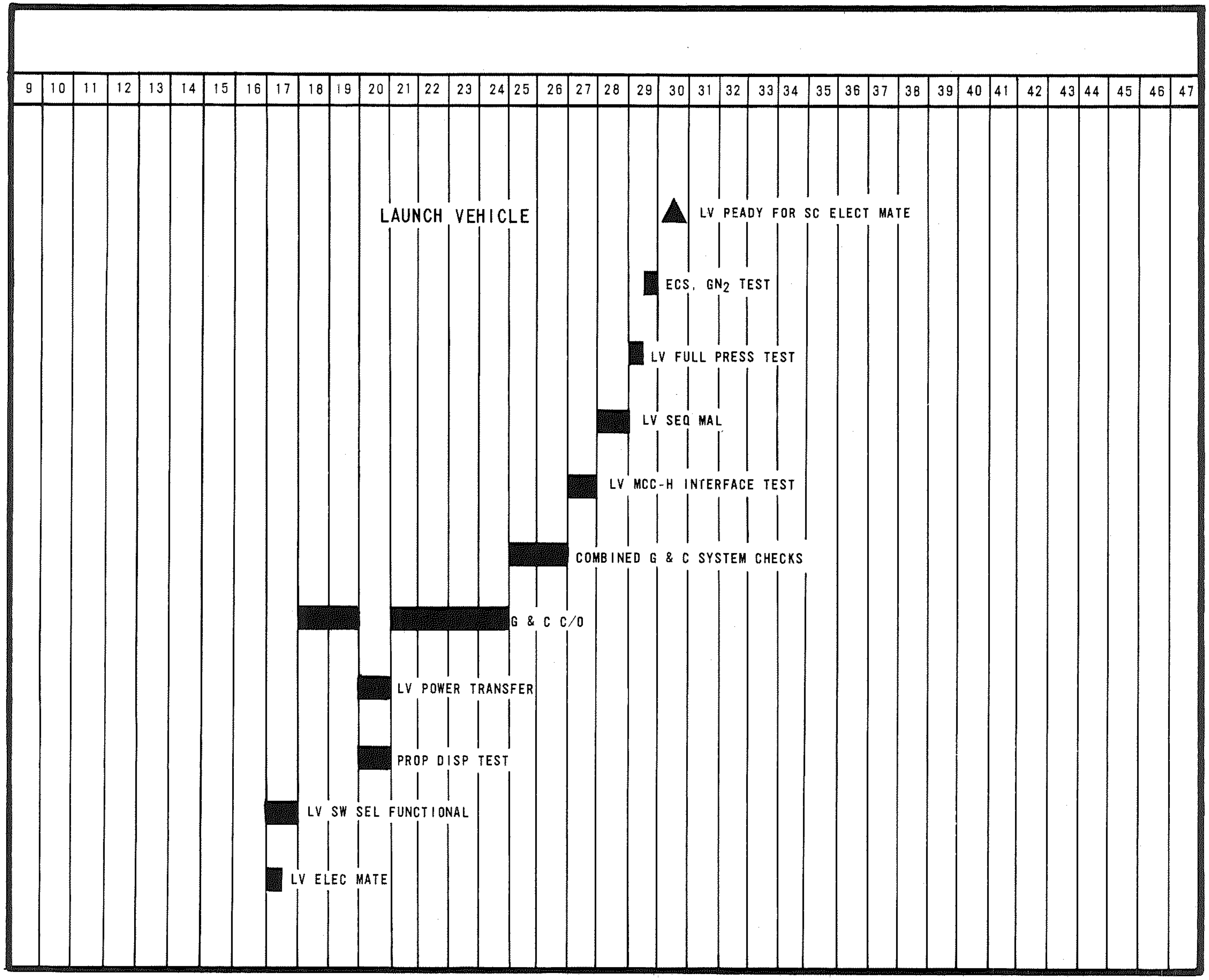

Figure 2-7. Typical Saturn IB/Apollo Launch Vehicle Time-Based Functional Flow

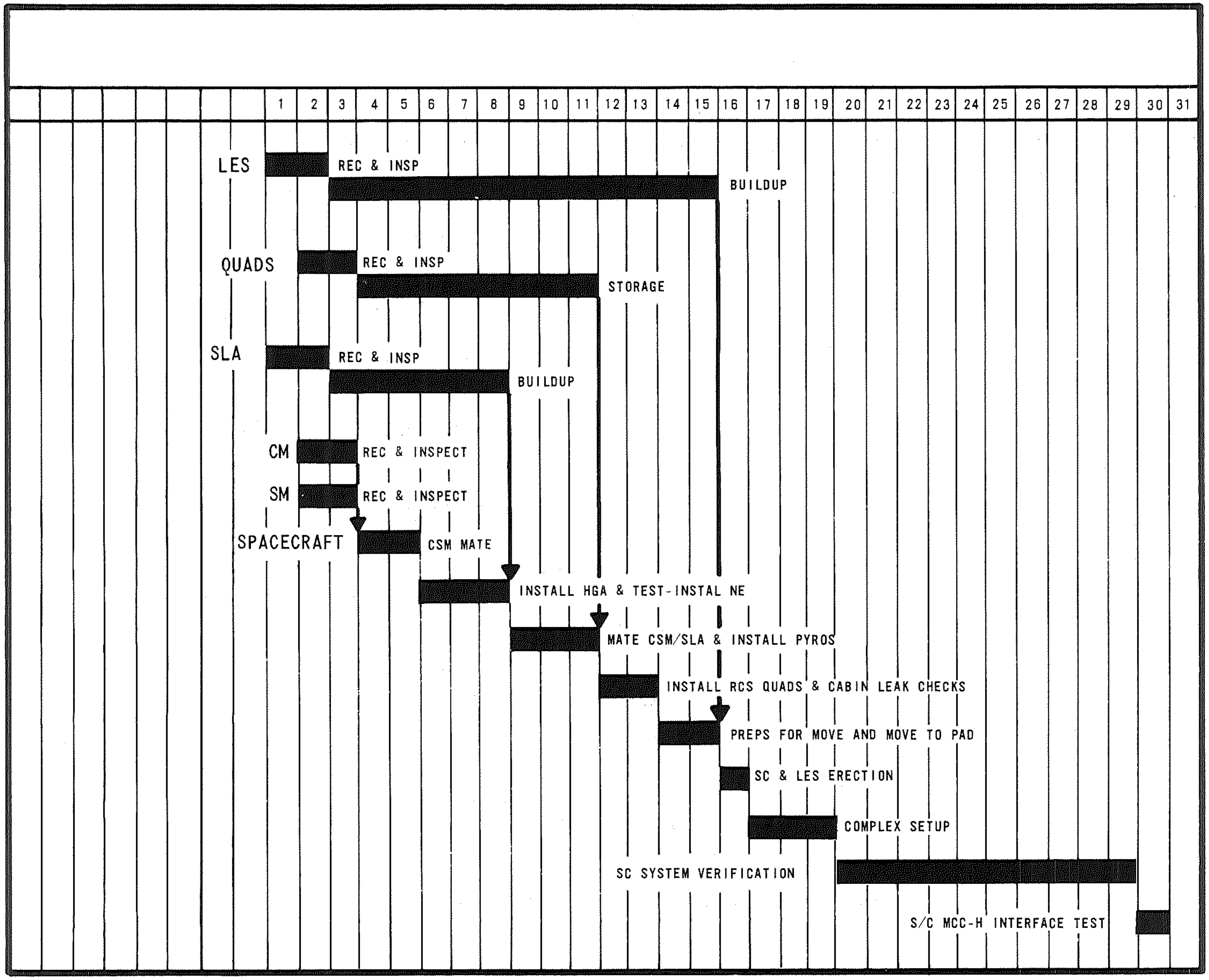

Figure 2-8. Typical Saturn IB/Apollo Spacecraft Time-Based Functional Flow

For spacecraft checkout, the command and service modules are mated in the high altitude chamber for systems verification, followed by installation of the high-gain antennas and nozzle extenders on the service module engine. The command and service modules and the service module/lunar module adapter are then mated and pyrotechnics installed. Installation of the reaction control system propulsion quads and cabin leak checks are completed and the spacecraft is moved to the launch pad. There, the spacecraft and the launch escape system are erected. Prior to spacecraft electrical mate to the launch vehicle, the spacecraft complex is activated, spacecraft systems verified, and a Mission Control Center-Houston interface test is performed. The space vehicle is then mated electrically to the launch vehicle.

3. Space Vehicle Functional Flow

The space vehicle flow (Figure 2-9) is then started. This consists of an emergency detection system test, umbilicals-in overall test, umbilicals-out overall test, space vehicle ordnance installation, flight readiness test, hypergolic preparation, loading and auxillary propulsion system static firing, preparations for the countdown demonstration test which includes RP-1 fuel loading of the first stage, a space vehicle Mission Control Center-Houston interface test, and the countdown demonstration test.

4. Launch Countdown Functional Flow

The space vehicle is now ready to enter launch phase; the phase is divided into two parts and performed on successive days. The first day consists of launch vehicle preflight preparations and the exercising of various systems to obtain final verifications. This is followed by the installation and partial connection of ordnance. Spacecraft operations consists of verification of all ground support equipment connections and application of power to the spacecraft buses. Onboard displays are calibrated in quantitative systems tests, utilizing automatic checkout carry-near equipment.

During systems checks, the pyrotechnic buses are armed and stray voltage checks are performed. Upon completion of stray voltage checks and system validations, power is removed and all initiators and spacecraft flight batteries are installed after the carry-on equipment is disconnected.

The second day of launch vehicle countdown consists of battery installation, power transfer in which all launch vehicle systems are exercised, final range safety command checks, radio frequency and telemetry checks, and remaining ordnance connections. Spacecraft operations consist of a qualitative system test using telemetry hardline and radio frequency communications. Onboard displays are validated at this time. Final system verifications are then completed in time for the terminal count sequence.

The mobile service structure is moved to its launch position prior to start of cryogenic loading. Before loading of liquid hydrogen begins, the blockhouse is sealed. During the terminal count, but prior to initiation

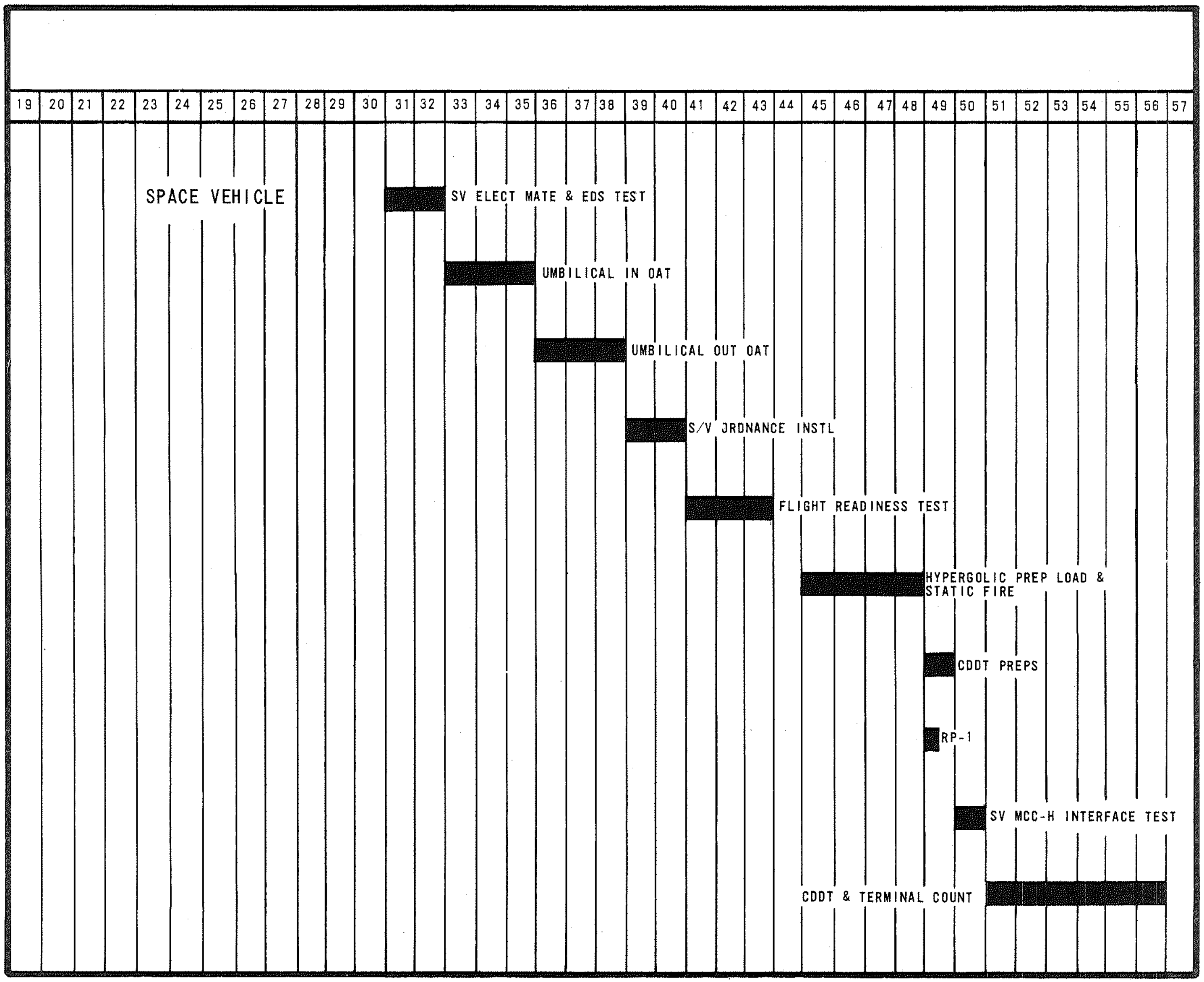

Figure 2-9. Typical Saturn IB/Apollo Space Vehicle Time-Based Functional Flow

of the launch sequence, all launch vehicle systems are activated and evaluated for performance. The automatic sequence activates all remaining functions required for liftoff. Procedures for emergency and recycle securing operations are included in the countdown procedures.

5. Schedule Changes

The schedule is planned prior to vehicle arrival. However, problems arise which cause real-time deviations from this schedule. These problems are resolved by the combined use of a 14-day vehicle test schedule (with the first 72 hours given in detail) and a daily work schedule, containing day-by-day activities covering the period from stage arrival to mating. These are released on a weekly basis.

A daily status meeting is held during vehicle checkout. Highlights of vehicle checkout progress are reported at the status meetings. The purpose of these meetings is to:

a. Summarize the day's activities and record status and progress.
b. Review problem areas.
c. Revise the schedules to reflect problems and progress.
d. Review the next three day's activities so that detail work can be scheduled.

D. TEST OPERATIONS

Launch vehicle checkout operations, utilizing the control and checkout systems, can best be illustrated by describing the operations during one of the major Saturn V space vehicle overall tests.

The control and checkout systems consoles, located in the launch control center, are operated by system test engineers and technicians. Through the utilization of these consoles, the test engineer initiates, controls, and monitors all of the launch vehicle systems tests. The launch vehicle and stage test conductors, located at consoles in the management area (Area A, Figure 2-10), control the sequence of initating the tests in accordance with the approved procedures and countdown document. The launch director, other launch operations management personnel, and representatives of the development centers are also located in area A.

The space vehicle overall umbilical eject test (Figures 2-11 and 2-12) will be used as an example of checkout because of its close resemblance to actual flight conditions. The test has four major phases:

1. Support preparations and power-up.
2. Prelaunch countdown.
3. Flight sequence.
4. Post-test operations.

The test objectives are to verify proper operation of all space vehicle systems and associated control and checkout equipment during a normal automatic firing sequence and flight sequence; this includes hold-down release, electrical umbilical ejection, firing of live ordnance in test chambers, and verifying the absence of electrical interference at the time of umbilical disconnect.

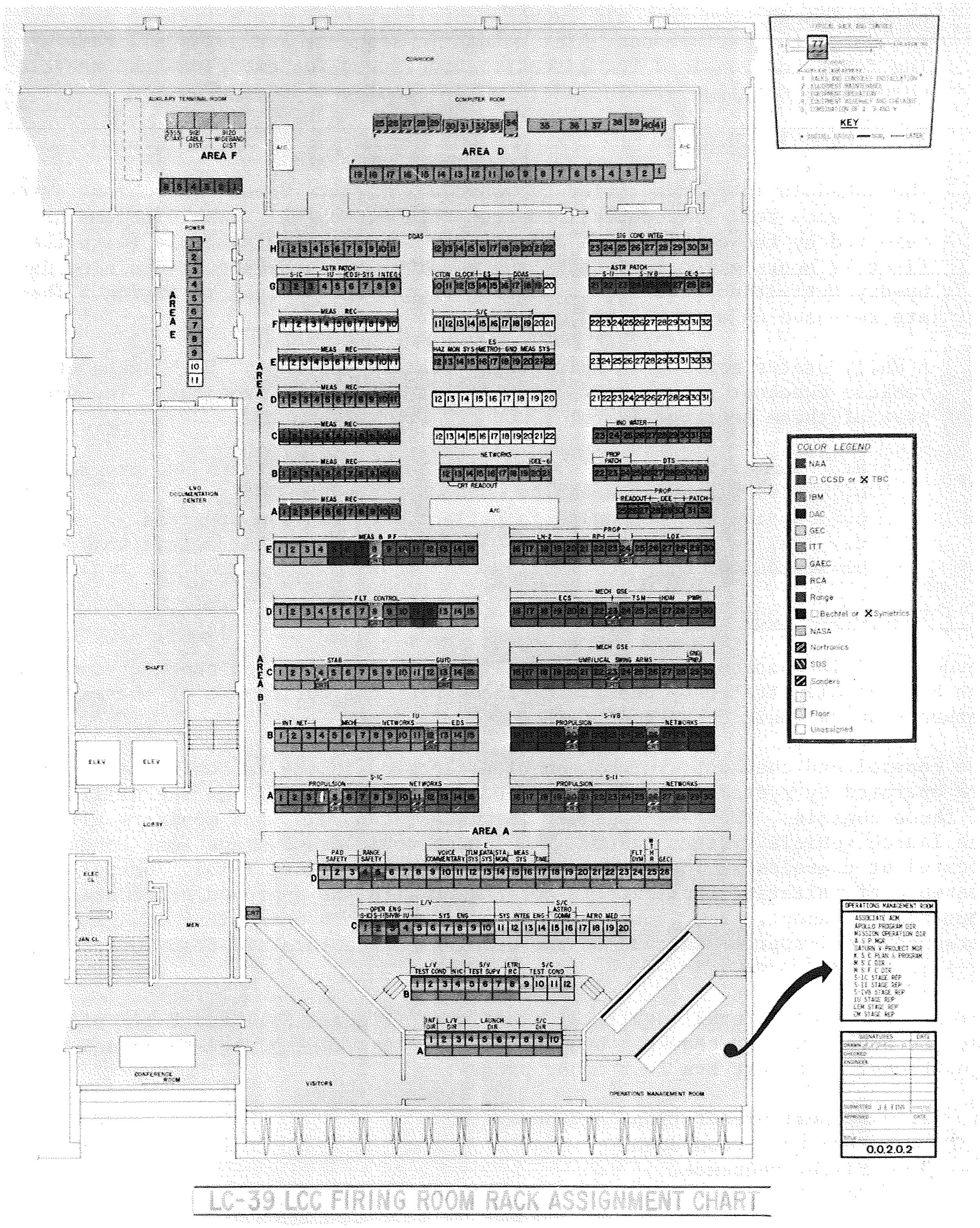

Figure 2-10. Rack Assignment Chart, LCC Firing Room, Launch Complex 39

All launch vehicle telemetry and range safety command receivers operate through closed-loop cables. The launch vehicle RF and tracking systems (C-band beacons, control and command, global tracking, and offset doppler) will be monitored at the vehicle assembly building by the RF checkout equipment using repeater antennas. Propellant dispersion system command functions for the stages will be given at the proper time.

The launch vehicle countdown picks up at T-7 hours 45 minutes with installation of live ordnance items and flight batteries, during which time RF silence is maintained. At T-7 hours 5 minutes, the support preparations and power-up phase begins.

Major support preparations involve three major items: the electrical systems, the Saturn ground computer complex, and the digital data acquisition system. The primary concern with the electrical systems are cable hook-up, control and checkout systems facility power application, the digital event evaluator computer verification, and the countdown clock system functional checkout.

The Saturn ground computer complex system performs the necessary preventive maintenance checks on all computers. Computer acceptance and interface test programs accomplish computer self-check and interface checkout of the following: digital data acquisition system, discrete system, countdown clock, launch vehicle digital computer and data adapter, and spacecraft interface. The computer verification and interface checks are all performed in the proper sequence followed by the functional tests of the other systems.

The digital data acquisition system is functionally checked and is committed to operational use after completion of the Saturn ground computer complex interface test. When the discrete and countdown clocks interface checks are completed, the Saturn ground computer complex starts initialization procedures by loading the operating program into the computer and activating all the computer input/output interfaces, except the discrete output. The computer complex is now in the IDLE mode.

The count is now T-5 hours 5 minutes and the switch scan program is called up and executed. This program scans all operator switch positions and signals from the vehicle and compares these signals with a predetermined status, printing out all differences. The operators at the systems consoles set the switches to the correct positions, and the discrete output system is activated. The computer complex now is in the GO mode, completing activation of the control and checkout system.

The launch vehicle environmental control system is activated followed by stage and instrument unit power-on and functional checks of the electrical and mechanical systems. RF silence is maintained until completion of the live ordnance installation in the test chambers.

The countdown is now T-3 hours and the countdown displays are activated. This signifies the start of formal operating steps. Launch vehicle instrumentation and guidance checkout now begins.

All RF systems, global tracking, offset doppler, control and command system, C-band beacon, and range safety command receivers are functionally checked,

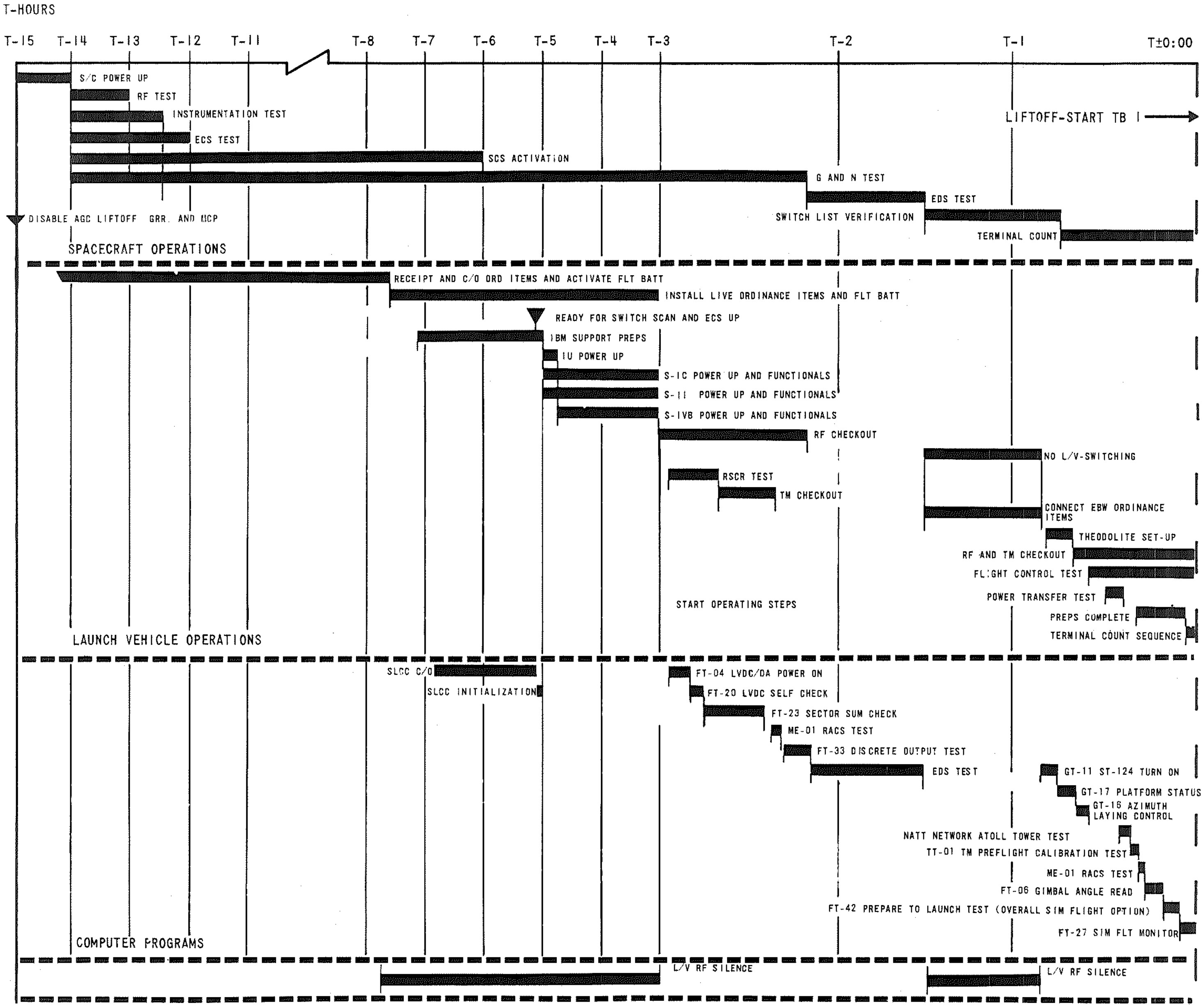

Figure 2-11. Typical Saturn V/Apollo Overall Test/Umbilical Out-Countdown

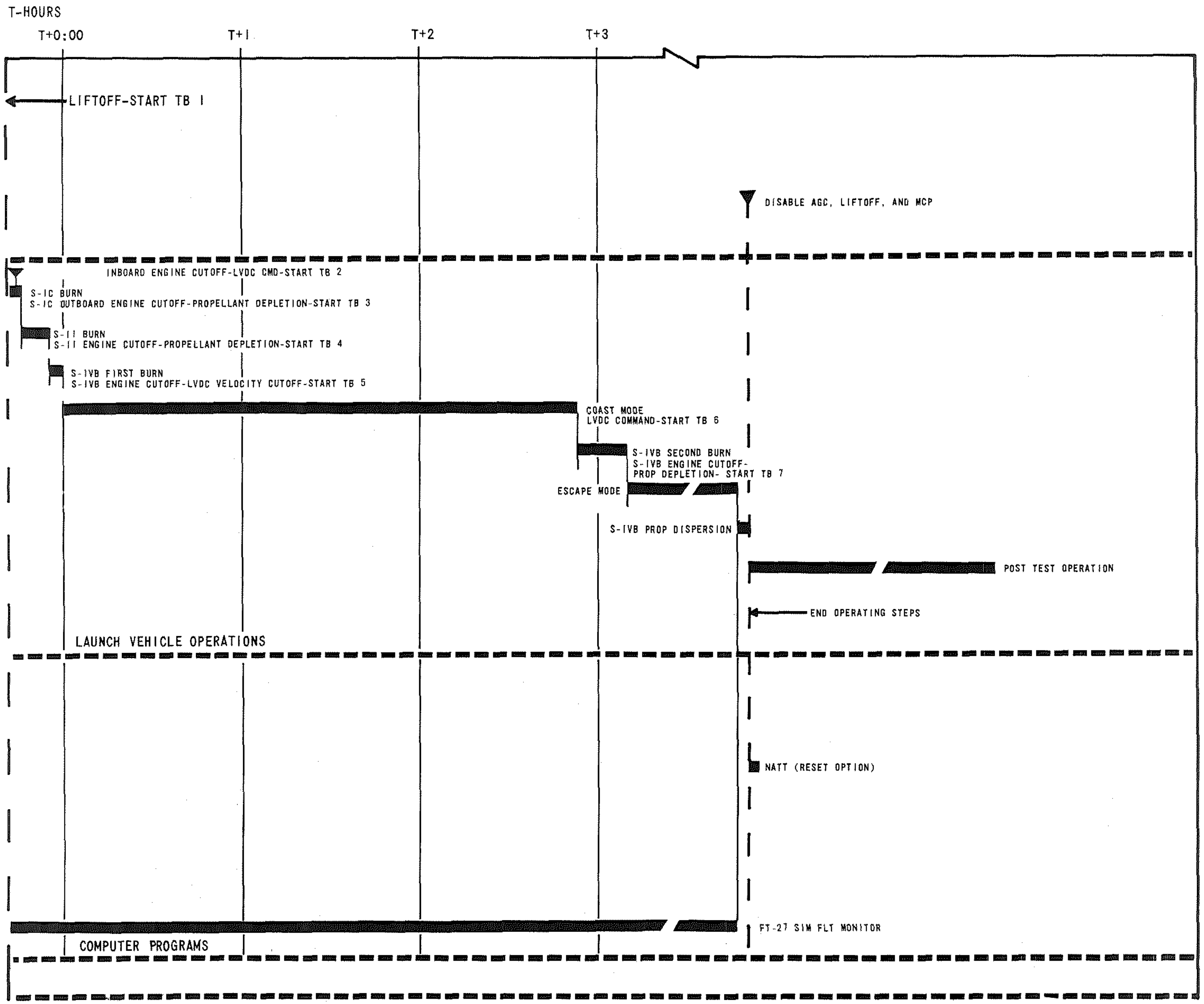

Figure 2-12. Typical Saturn V/Apollo Overall Test/Umbilical Out-Flight Sequence

followed by commands from the Range Safety Officer. The stage telemetry systems are activated and a calibration check is made. All vehicle sensors and signal conditioning is verified at the test engineer's measuring station prior to initiating the remote automatic calibration system test. This test and a functional check of the launch vehicle guidance and emergency detection system are all performed automatically, utilizing test programs previously loaded into the Saturn ground computer complex. These tests are called up for execution in the proper sequence through the display console keyboard. The guidance test consists of:

1. <u>Launch Vehicle Digital Computer/Launch Vehicle Data Adapter Power-On</u>

This procedure checks each redundant power supply, communication between the computer/data adapter and the Saturn ground computer complex, power-up sequencing, and activation of the computer memory system.

2. <u>Self-Checks</u>

Complete logic and computer operations.

3. <u>Sector Sum-Checks</u>

Validation of memory.

4. <u>Preflight Command Test</u>

Mission Control Center-Houston issues commands via the unified S-band system for word and sector dumps. The Central Instrumentation Facility provides real-time analysis of this test by reading the vehicle telemetry system and processing the necessary data.

5. <u>Discrete Output</u>

Check of discrete output commands.

The vehicle measuring system test consists of switching the signal conditioning inputs from normal mode to high, then low calibration. A comparison is made with the nominal values and any errors are displayed.

The vehicle emergency detection system utilizes spacecraft checkout computer/ground computer complex, in addition to all the launch vehicle control and checkout system interfaces necessary to accomplish its objectives. There are two modes associated with this test. Each of the modes verify the system by permutating relay logic and emergency detection system control rate gyros, using all redundant paths.

1. <u>Mode One</u>

Engine out abort circuitry and excessive rate circuitry.

2. <u>Mode Two</u>

Launch vehicle and spacecraft abort circuitry.

Throughout the test, resultant vehicle discrete and digital data acquisition system signals are compared against desired responses; all discrepancies are displayed. The operator is given the option to retest, stop, or continue the test.

At T-1 hour 30 minutes, all vehicle switching is stringently controlled and RF silence is maintained during the connection of the explosive bridgewire ordnance items. When the count reaches T-50 minutes and after RF silence is released, all systems prepare for the launch vehicle power transfer test.

1. RF and telemetry systems are turned on for the last time and flight telemetry calibrations are made.

2. The flight control system is functionally tested without engine actuator hydraulics. Prior to power transfer, an error signal is set into the control computer and the hydraulic pumps are turned on so that complete control engine actuator servo loops can be checked when the vehicle is on internal power.

3. The launch vehicle inertial platform and automatic alignment system checks consist of validation and setup of the alignment system and execution of the following test programs:

   a. Platform Turn-on. Verification of proper power and gaseous nitrogen, sequencing of power, gyro and accelerometer servo loop checks and alignment.
   b. Platform Status. Verification of all platform parameters.
   c. Azimuth Laying Program. Position the platform to the prescribed flight azimuth.

Power transfer is initiated at T-29 minutes. The flight-type batteries, located in the overall test room, and all flight systems are closely monitored. The launch vehicle is then returned to external power. Starting at T-24 minutes, the remaining test programs are called up in sequence and executed. These consist of the following:

1. Network simulation test that functionally checks and sets up the overall test equipment used to provide simulated vehicle functions in the plus count.

2. Telemetry preflight calibration test.

3. Remote automatic calibration.

4. Platform gimbal angle read.

5. Launch vehicle digital computer prepared-for-launch routine (simulated flight option), which puts the computer in the proper mode to receive guidance alert, guidance release, and to sense liftoff. (Guidance release, when received by the control and checkout system, commands the stabilizer platform to the inertial mode.)

6. Simulated flight monitor, which monitors all of the flight sequence commands.

At T-3 minutes 7 seconds the automatic launch sequence is started issuing all necessary commands for engine ignition and lift-off. Lift-off starts the flight sequence phase of the test.

From this point on, the space vehicle is essentially isolated from the control and checkout systems except for some critical circuits that are required to ensure safe control of the vehicle and to reinitialize ground control if the need should arise. The actual flight program of the vehicle is used by the launch vehicle computer which, in addition to solving the complex guidance problems, provides the proper sequencing of all necessary functions.

E. POST-TEST OPERATIONS

The post-test operations involve two major functions: reestablishment of the space vehicle system with the control and checkout equipment and detailed evaluations of all vehicle systems performance. The reestablishment of the vehicle with the ground system consists of a complete inspection of all disconnected umbilicals, reconnecting, resetting of required vehicle systems, and a complete power shutdown.

The post-test critique, conducted immediately following the completion of the test, is normally an open discussion where the performance of each system is discussed and any anomalies reported as seen by visual observations, and from information received by real-time analysis.

The launch vehicle control and checkout systems provide time-history printouts of all discrete 28-volt signals sensed or issued by the Saturn ground computer complex and all 28-volt signals sensed by the digital event evaluators. Special post-analysis programs are used to check time relationships between any combination of discretes for any time period. This data is available to aid in the evaluation of launch vehicle control and checkout system performance.

The Central Instrumentation Facility provides all flight system data processing. Quick-look data is usually available in six hours. Complete post-processed test data is usually available one working day following the test. The data, consisting of X-Y time plots, oscillograph strip charts, and digital printouts are displayed in special evaluation rooms. All of these records include range timing and are marked for significant event occurrences such as ignition, liftoff, stage cutoffs, etc. Special printouts are provided to the launch vehicle guidance personnel.

Evaluation by the cognizant system test engineer consists of a complete examination for normal and abnormal system responses; this includes trends, drifts, oscillations, noise, relationships with other events, parameter values, and correct time of events. All anomalies must be resolved prior to continuation of vehicle checkout.

SECTION III
SPACE VEHICLE CONTROL AND CHECKOUT SYSTEM

INTRODUCTION

The Saturn/Apollo space vehicle control and checkout system (Figure 3-1) consists of five major systems tied together with stringent interface control that involves division of systems and subsystems functions. This portion of the discussion concerns three of these systems: launch vehicle instrumentation; Saturn ground computer complex; and electrical distribution and control. Together, these three systems constitute the Saturn/Apollo launch vehicle control and checkout system. The Central Instrumentation Facility and Spacecraft Checkout are discussed only where direct launch vehicle operations are involved.

Each system supplies command functions and makes intelligence information available to other systems and to operational personnel. The instrumentation system provides intelligence information of the total vehicle system whenever required. The Saturn ground computer complex provides both command functions and selectable intelligence information in the automatic or semiautomatic mode. The electrical distribution and control system provides both command functions and continuous intelligence information. Each system has the following features:

1. Timing inputs.
2. Built-in self check.
3. Built-in test points.
4. Extensive independence in operations.
5. Logging and recording devices.
6. Redundant paths.
7. Selectable real-time data retrieval and display.
8. Interrupt capabilities and priority control.

A. ONBOARD LAUNCH VEHICLE SYSTEMS

The vehicle systems provide the necessary control and monitoring of the launch vehicle throughout the Saturn/Apollo mission including the powered phase of flight, earth orbital injection, and coast. These systems are generally categorized as follows: Guidance & Control; Instrumentation; Electrical; and Mechanical. A typical Saturn IB vehicle systems flow is shown in Figure 3-2.

1. Guidance and Control

The guidance and control systems consist of the inertial platform, control, and launch vehicle digital computer/data adapter systems. These systems determine the vehicle's position and velocity, calculate the maneuvers necessary to achieve proper orbit, generate steering commands, and provide sequence control of the launch vehicle.

The inertial platform provides vehicle attitude and inertial velocity to the launch vehicle digital computer for determination of actual vehicle position and velocity. Attitude and velocity measurements are routed through the data adapter which is the input/output device for the computer.

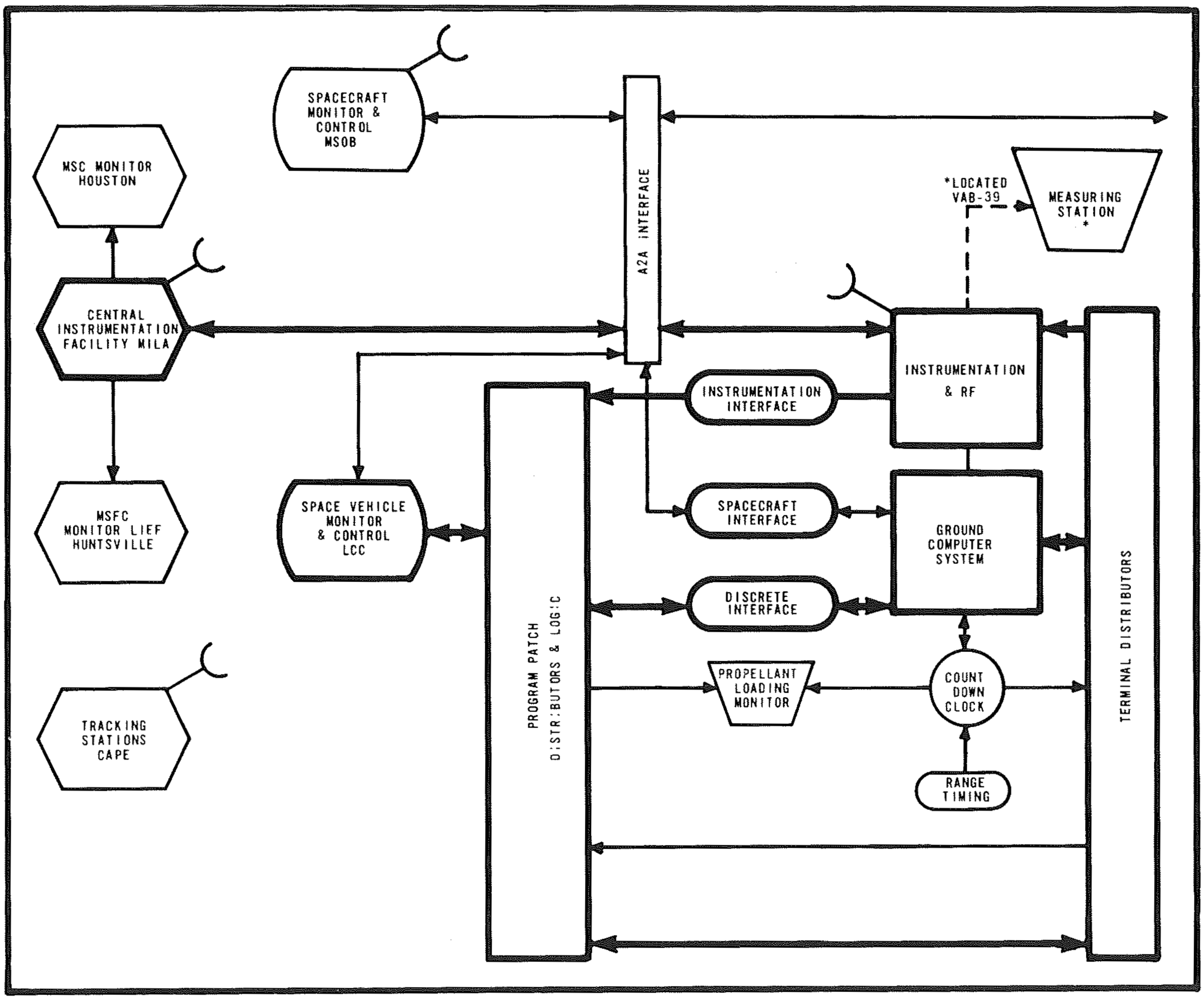

Figure 3-1. Saturn/Apollo Control and Checkout System (Sheet 1 of 2)

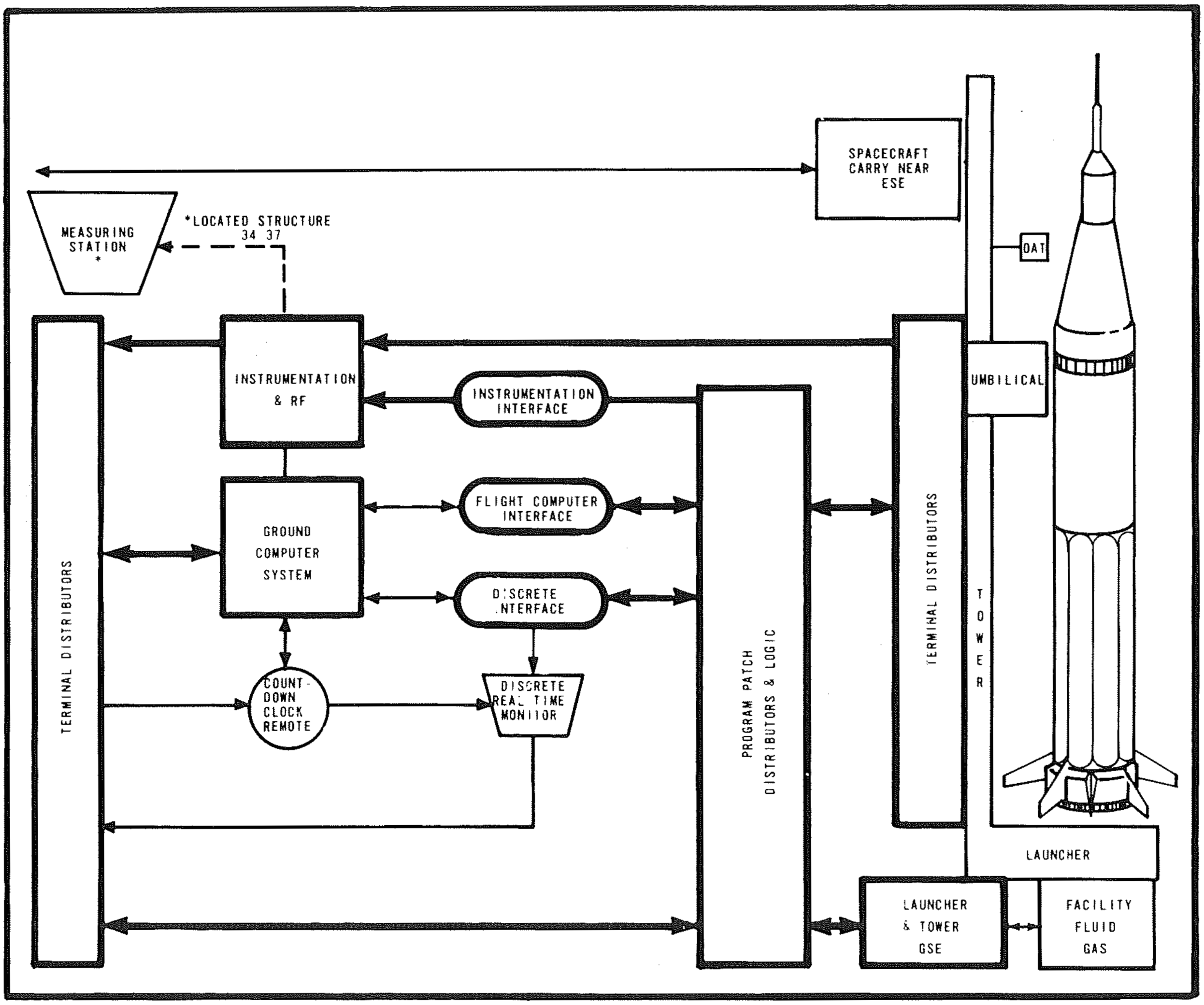

Figure 3-1. Saturn/Apollo Control and Checkout System (Sheet 2 of 2)

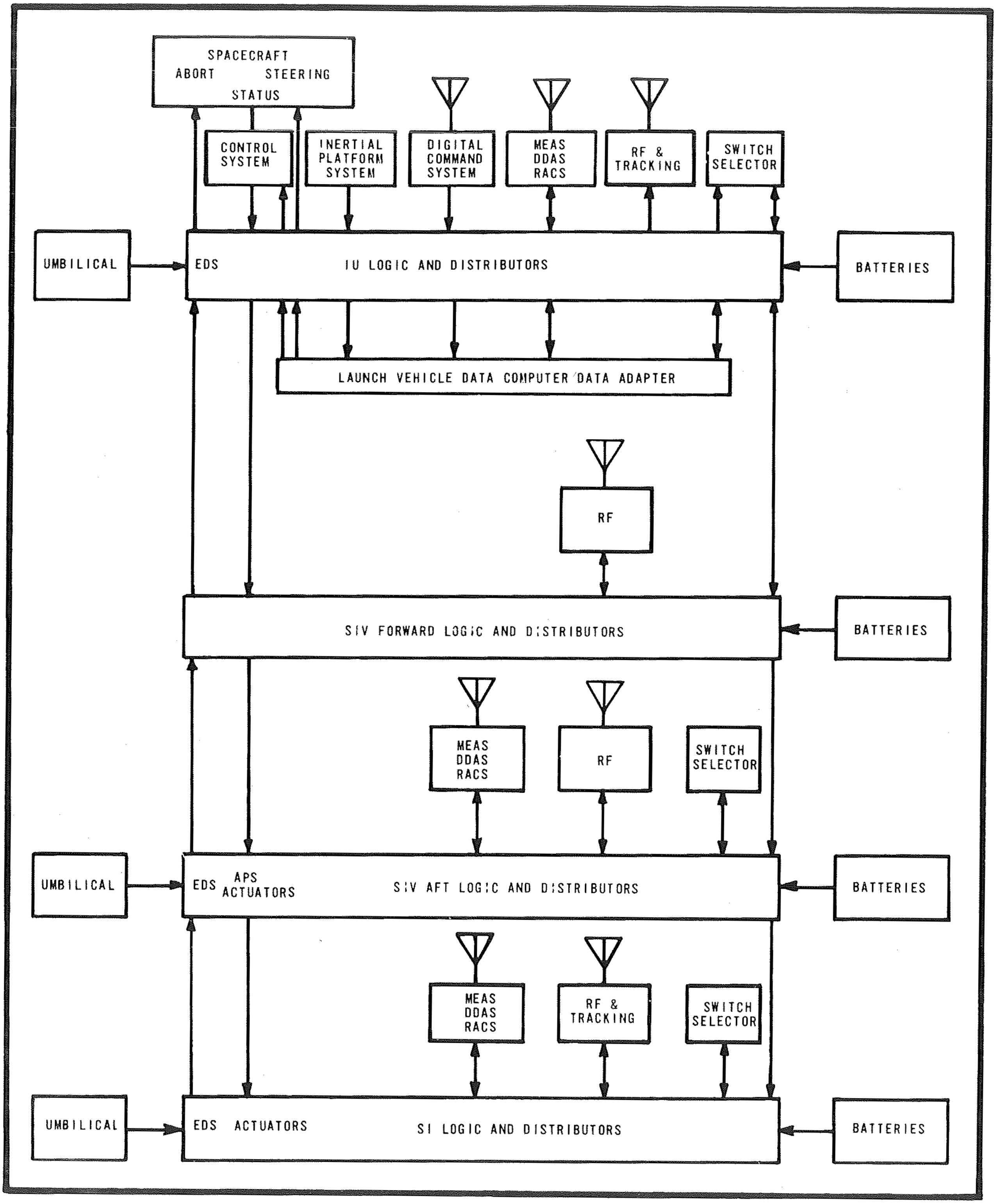

Figure 3-2. Typical Saturn IB Vehicle System Flow

The adapter buffers all discretes and provides analog-to-digital conversion of all data required by the computer. Within the computer, the actual attitude data is compared with the desired attitude computed from the information sent by the platform. The result is the required steering command and time-for-engine-cutoff. The control system combines the steering commands with the vehicle angular rate signals in the flight control computer. This computer is an analog device which sums, filters, and scales each of the signals, and commands the appropriate engine actuator and auxiliary propulsion system.

2. Instrumentation

The Instrumentation system is functionally divided into (1) Measuring/telemetry systems that measure and transmit data representing launch vehicle physical quantities to ground stations; and (2) Radio command/tracking systems that provide for data transmission to the launch vehicle digital computer, radio commands to the launch vehicle range safety systems,and continuous launch vehicle tracking during powered and orbital flight.

The measuring systems condition the signal, or quantities to be measured, for acceptance by the various stage telemetery links for transmission to ground stations. A remote calibration system permits calibration of all measurements prior to launch by substitution of high and low calibration signals from the transducer inputs to the signal conditioners. Each vehicle stage carries an independent telemetery system to modulate the measuring signal into radio frequency for transmission to ground stations. The telemetery systems in the launch vehicle utilize three different modulation techniques; PAM/FM/FM, SS/FM, and PCM/FM. A digital data aquisition system in each stage is associated with each PCM/FM telemetery system. This system time-integrates the PAM analog and digital signals into a single PCM output and transmits this information by coaxial cable or radio frequency to digital receiving stations located in the launch control center, or on the mobile launcher. A computer interface unit in the instrument unit provides the means for the launch vehicle digital computer to select desired vehicle data.

The range safety command systems, located in the propulsion stages of the launch vehicle, have the primary purpose of terminating the vehicle flight by radio command from the ground if the vehicle deviates beyond acceptable limits. Each stage system uses dual receiving antennas, power dividers, command receivers, and digital decoders all connected in parallel. The instrument unit command system consists of a command receiver, decoder, and antennas, and is used to receive and decode digital information transmitted from ground stations to the launch vehicle digital computer. Message verification is achieved by transmission over the PCM/FM system back to the ground stations. The launch vehicle carries several tracking transponders to provide continuous tracking during powered flight into earth orbit. A common antenna used for receiving and transmitting is provided for each transponder. Various ground stations throughout the world-wide tracking network provide precise real-time tracking for range safety and for post-flight evaluation.

3. Electrical

The electrical systems supply and distribute the power and control signals to checkout, monitor, and operate the various subsystems of the launch vehicle. Prelaunch ac and dc power is supplied from the ground support equipment, and inflight power is supplied by 28-volt batteries installed in the instrument compartments of the various stages. Distributors installed throughout the stages distribute power and control signals to the various subsystems. Flexibility in the distribution system is achieved by using separate distributors for power, control, measuring, and propulsion circuitry. The interface between vehicle circuitry and the ground support equipment is maintained through umbilical connections in each stage of the vehicle and on the short cable mast in the first stage. The philosophy of the launch vehicle sequential system is to utilize the launch vehicle digital computer for timing sequences whenever possible. To ensure compatibility between the launch vehicle digital computer and the other stages, a switch selector for each stage is used as an interface unit. A switch selector is basically a series of low power switches, the input of which is individually selected and controlled by a coded address word from the launch vehicle digital computer. The switch selector internally decodes the eight-bit address word and furnishes an output from one of 111 relay driver outputs. The design of the switch selector is such that any word or its compliment will give exactly the same output. In addition to being addressed by the launch vehicle computer, the switch selector may also be addressed from the ground computer or the manual panel in the launch control center through the umbilical connections.

4. Mechanical

The launch vehicle mechanical systems consist of the structure propulsion and propellant systems which provide the necessary controlled power thrust during all phases of flight.

Each propulsion stage structure contains a propellant tank assembly which is divided into separate containers for the fuel and oxidizer (RP-1 and liquid oxygen for the first stage, liquid hydrogen and liquid oxygen for the upper stages). The propellant system consists of components that load propellant from a ground source, store the propellant, and supply it to the engine system at the proper pressure. Hydraulic actuations of the gimbal engine system (four gimbaled engines on the lower stages and one engine on the S-IVB Stage) provide the necessary thrust vector control during powered flight. An auxillary propulsion system on the S-IVB stage provides roll control during powered flight and complete thrust vector control during the coast phase.

B. ELECTRICAL CONTROL AND DISTRIBUTION SYSTEM

The control and checkout system is comprised of numerous individually operated elements of ground support equipment and a multistage vehicle that are widely separated in physical location, yet completely integrated into one complex system. This presents the complex task of maintaining the interconnecting communication line necessary for continuous control and monitor. The three separate areas of the launch complex (the launch control center, pad/automatic ground control station or mobile launcher, and the space vehicle) are connected by permanent long-run, multiconductor and coaxial cable runs. The cables have terminal distributors at each end to provide termination and distribution points. A distribution flow diagram is shown in Figure 3-3.

Further distribution at each area is accomplished by utilizing programmable patch distributors connected by shorter multiconductor cables to the terminal distributors and to all ground support system equipment. Any signal originating at a vehicle component and arriving at the mobile launcher program distributor, via the power terminal distributor, can be routed to the launch control center and then rerouted by patching to the appropriate control panel. Another signal leaving the same umbilical connection on a different conductor may arrive, by patching, at the electrical support equipment computer interface. This system has virtually eliminated the need for specially built multiconnector spider cables, and provides the maintainability necessary to keep pace with the vehicle and ground support equipment changes.

Numerous programmable distributors are either stage or system oriented for use in interconnecting the equipment within a given system,or may be designated as integration distributors used to provide the buffering between different stage electrical support equipment. Each distributor contains the circuit logic required to interlock control functions for equipment and personnel safety, and to properly sequence functions during checkout operations.

1. Sequencers and Power Subsystem

Included in the electrical control and distribution system are the power subsystem and the terminal countdown and ignition sequencer. In the Saturn IB, the terminal countdown sequencer is located in one of the launch control center panels. The sequencer is a relay device consisting of three decimal counters and output gating utilized during the final 163 seconds of the countdown to perform such functions as propellant tank pressurization, switching from external to internal power, and start and termination of liquid oxygen bubbling. The sequencer operates on a one-pulse-per-second signal from the countdown clock and is started manually.

TCS

The ignition sequencer located in the launch pad area is a solid state device started at T-3 seconds by a signal from the terminal countdown sequencer. A 400-cycle per second input signal drives binary counters within the sequencer. The output of the counters is gated to the output relay driver circuits to produce four 28-volt output signals at 100-millisecond intervals. The sequencer is used to provide the ignition start signals for the booster stage. In the Saturn V system, both the terminal countdown and ignition sequencers are combined into one solid-state device located in the mobile launcher.

Power requirements for ground support equipment and for the launch vehicle prior to power transfer to internal batteries is provided from 28-volt power supplies and 400-cycle per second generators and static inverters, located in the launch control center and at the pad area. The 28-volt dc supplies are backed up with 30-volt dc emergency batteries. In the event of a power supply failure, the bus monitor circuitry will automatically

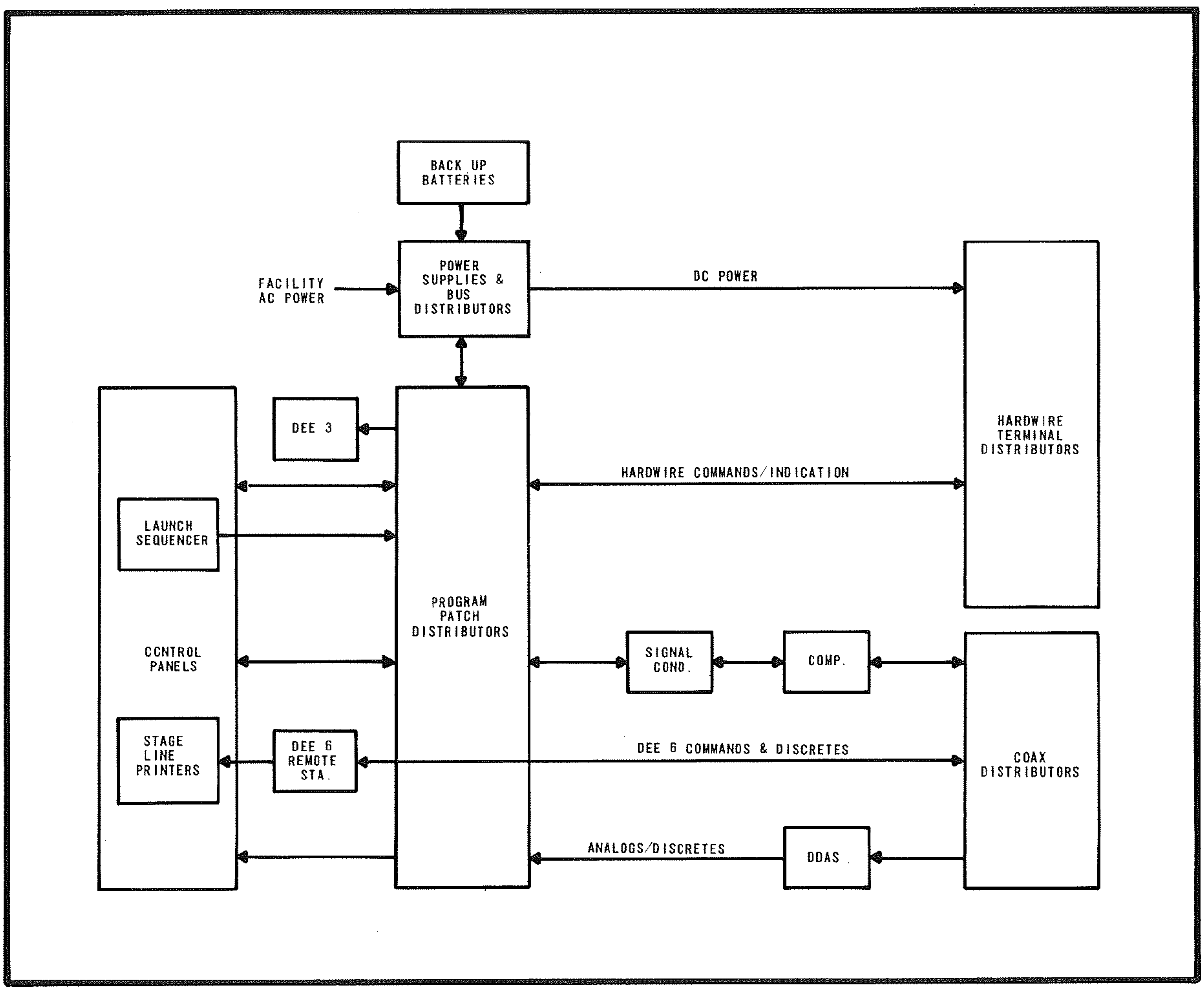

Figure 3-3. Electrical Control and Distribution Flow Diagram (Sheet 1 of 2)

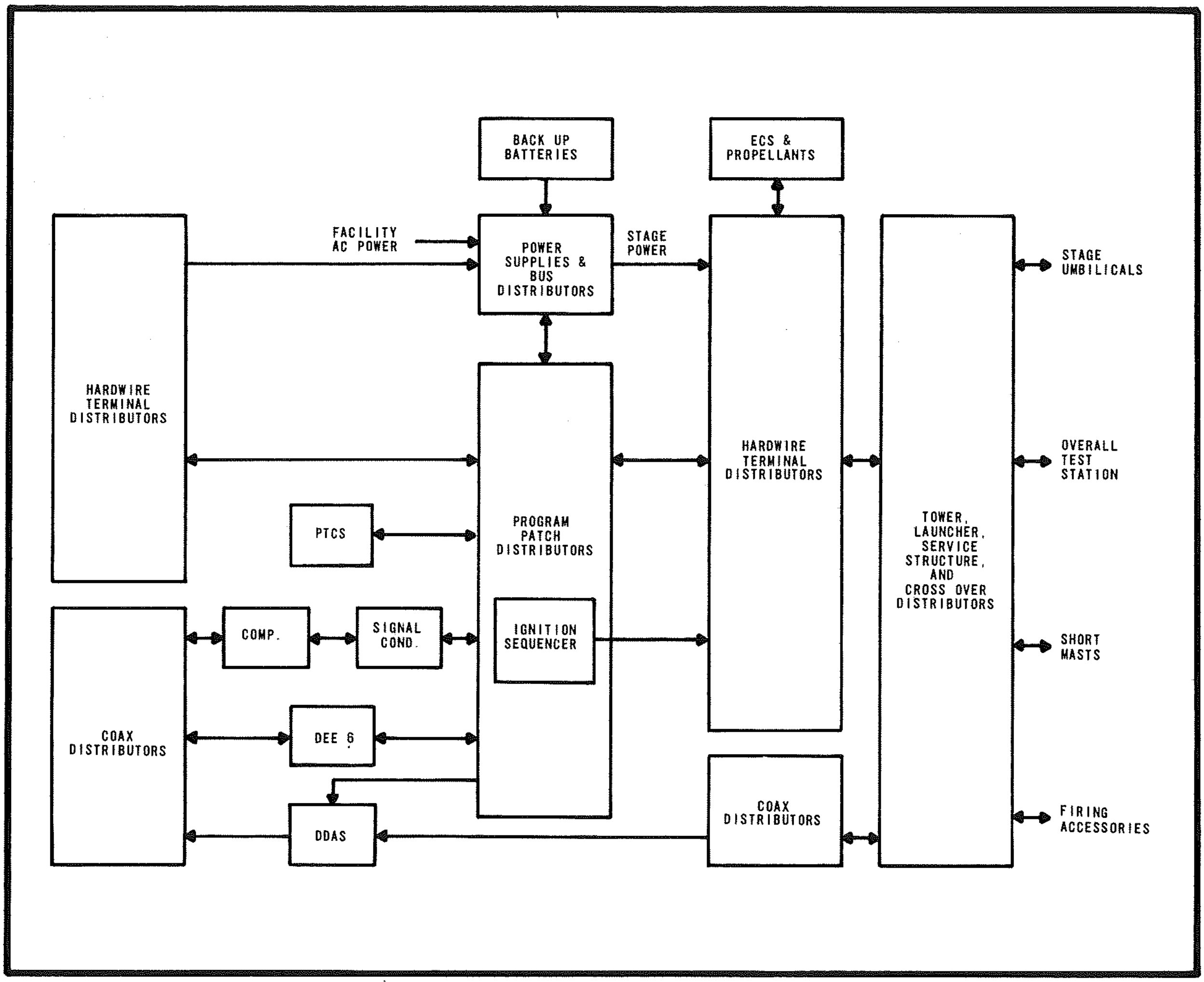

Figure 3-3. Electrical Control and Distribution Flow Diagram (Sheet 2 of 2)

switch the bus to the 30-volt battery tap. An auxiliary 24-volt battery tap is also provided to maintain the bus voltage at a minimum value during switching. The power supplies are normally controlled and monitored from the LCC. Local control is also available by removing the power supply control cable and installing a blind plug to activate the local controls and indicators.

2. Propellant Loading

The propellant loading system provides storage and transfer facilities for the three types of propellants (RP-1, liquid oxygen, and liquid hydrogen) used in the vehicle stages. There are two modes of operation for any fill or drain sequence: (1) automatic with manual override, and (2) a simulate mode for test purposes that permits checkout of the system without flow of propellant.

All vehicle stage tank loading operations are similar and consist of the following, as shown in Figure 3-4. Command or monitor functions on the control and monitor panels, located in the launch control center, are transmitted to or from the pad storage area, mobile launcher, and pad terminal connector room by a digital transmission system. Launch Complexes 34 and 37 utilize hardwire for this purpose. The electrical signals are used to control pressure for operation of the appropriate valves in the storage area and mobile launcher. When the system is operating in the automatic mode all commands are sequenced from relay logic located in the propellant system network patch distributor in the pad terminal connector room.

The propellant tanking computer system (Figure 3-5) accurately determines the quantity of propellant on board each stage tank, conditions this information for use by the propellant control network and controls the replenishing cycle. The digital event evaluator records discrete events and transmits discrete status to the line printer, in the launch control center. The propellant tanking computer system (an analog device) provides independent control of each vehicle tank and has an independent manual mode of operation. Each individual propellant tank has a complete computer system which compares propellant-level-indication inputs from a level-sensing system, aboard each vehicle tank, with a reference standard. In the computer, the signal is filtered and introduced to a summarizing network, where the "level" signal is compared with the reference signal whose value is equivalent to a 100 percent flight mass. The error signal is amplified and routed through the propellant networks to the automatic valve control assembly. Here the signal is used to control pressure which in turn controls the setting of the replenish valve. The filtered signal is also fed into a ratiometer and converted into a pneumatic signal equivalent to the propellant tanks level (in percent). This signal is then routed into the discrete generator where it is compared with preset discrete values (level points). As each one of these specific points is reached, a signal is transmitted to the propellant control networks. The automatic filling cycle for the propellant tanks is a precisely organized sequence of events controlled by the specific tank levels. If a malfunction occurs in the automatic mode, the operator can switch to the manual mode which provides a digital signal input to a digital-analog converter. The analog output is then fed through an amplifier to the manual value control assembly, which also adjusts the replenish value. The operator can also introduce discrete signals into the propellant control networks.

The data transmission system (Figures 3-6 and 3-7) is an integral part of the propellant loading system at launch complex 39. There are two similar system configurations. One is located in the launch control center and the other at the pad terminal connection room. Each features a MODEM (Modulator-Demodulator) with timing and logic input and output processing provisions. The system receives, multiplexes, and transmits control signals and status information between the launch control center panels and the systems patch rack in the pad terminal connection room. Zero or 28-volt dc discrete signals (1464) and zero to 5-volt dc analog signals (104) are processed and transmitted from the pad to the launch control center. Discrete signals (952) are processed in the reversed direction.

The digital event evaluator (Figure 3-8), located in the pad terminal connection room at launch complex 39 and in the launch control center at launch complex 34 and 37, provides a real-time record of propellant loading events. This system consists of a digital computer, teletypewriter, a line printer and coupler, a magnetic tape unit, and a data aquisition and evaluation cabinet. A total of 768 input signals are detected and recorded. The teletypewriter is used for direct operator control. The data aquisition and evaluator system scans the status of all discretes and compares each state with the previous state. All detected changes are printed out on a 600 line-per-minute printer as well as on magnetic and paper tape.

3. Launch Control Center

The firing room in the launch control center (Figure 3-9) provides the man-machine interface that allows the test engineer to control and monitor the Saturn V/Apollo checkout system. The control consoles are stage and system oriented for operational convenience, and perform the following functions:

a. Initiates command functions from the control panels and computer display console.

b. Monitors vehicle and checkout system responses.

c. Preserves critical measurements for permanent record and evaluation on strip chart recorders.

d. Visual surveillance of remote areas of the launch complex via the operational television system.

e. Maintains correct operational sequence by utilization of the operational intercommunications system and the countdown clock readouts.

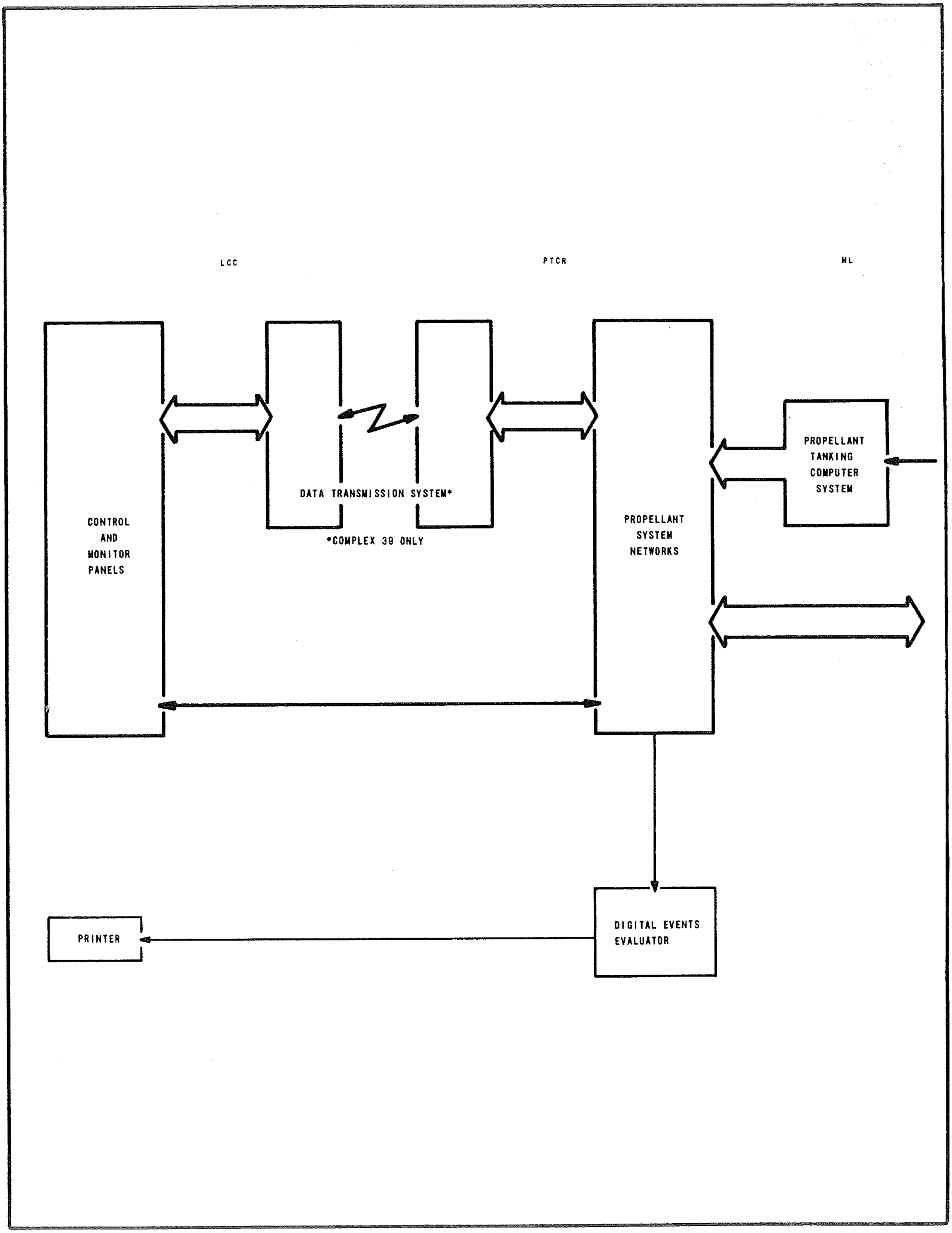

Figure 3-4. Propellant Loading System Functional Diagram (Sheet 1 of 2)

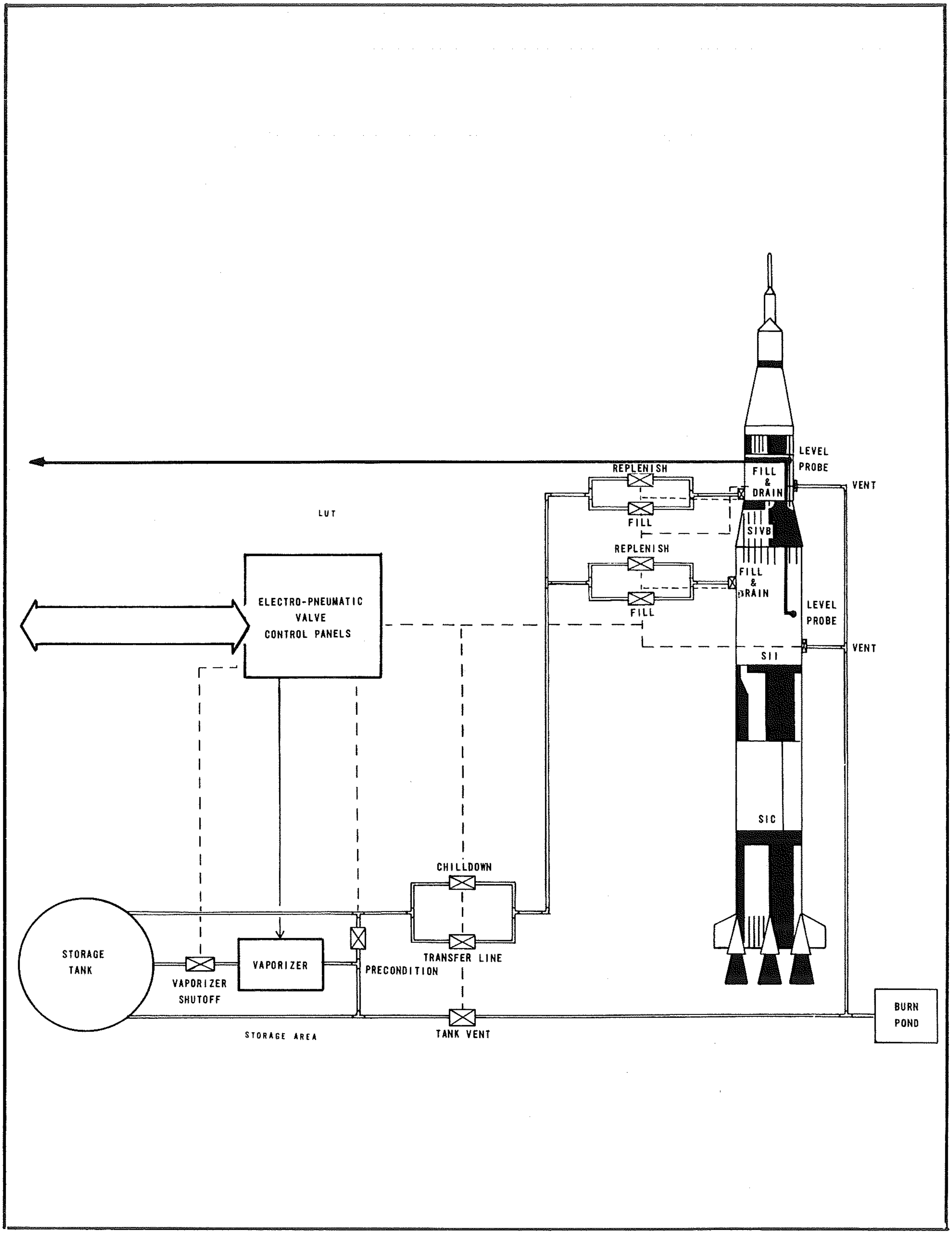

Figure 3-4. Propellant Loading System Functional Diagram (Sheet 2 of 2)

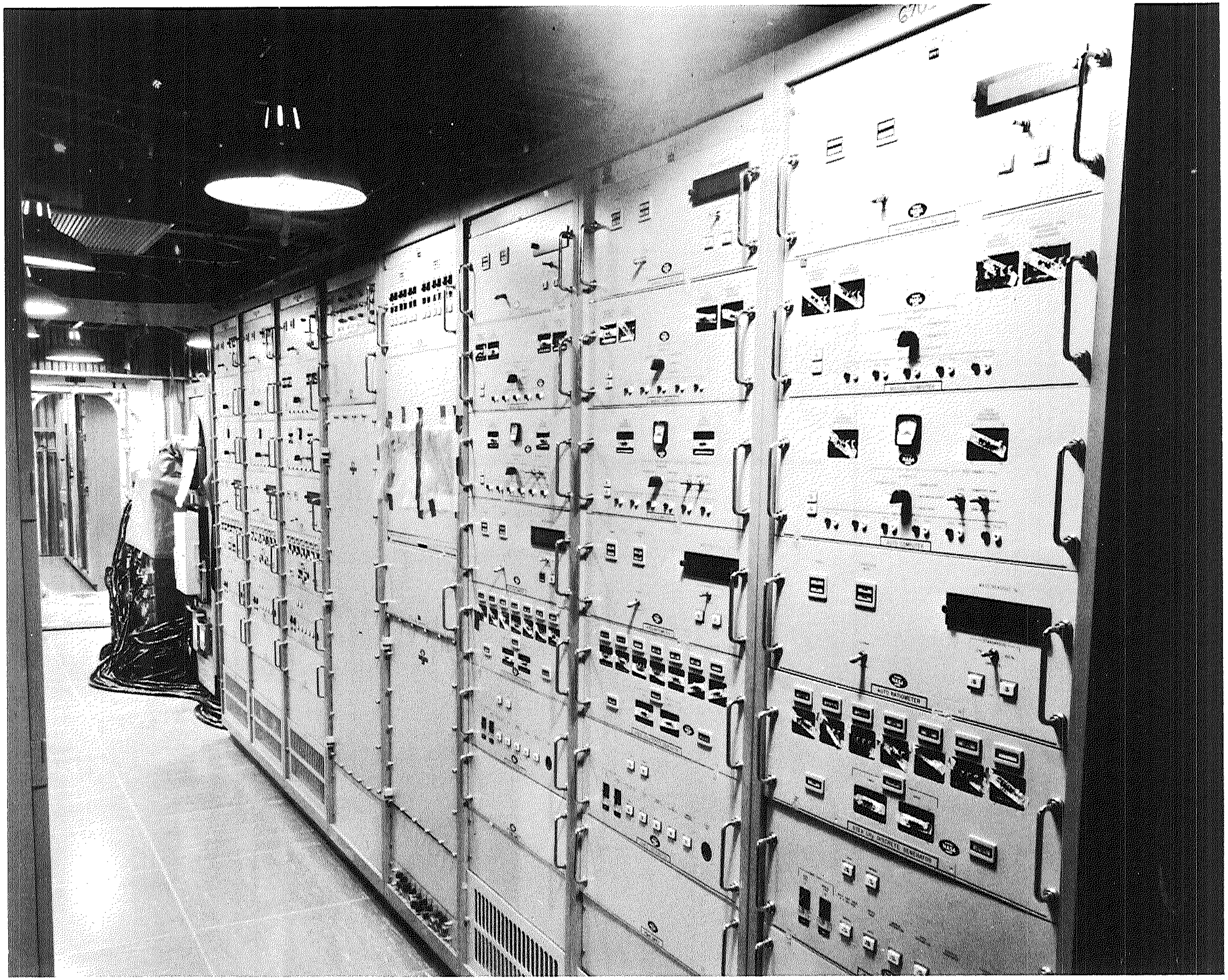

Figure 3-5. Mobile Launcher Propellant Tanking Computer System

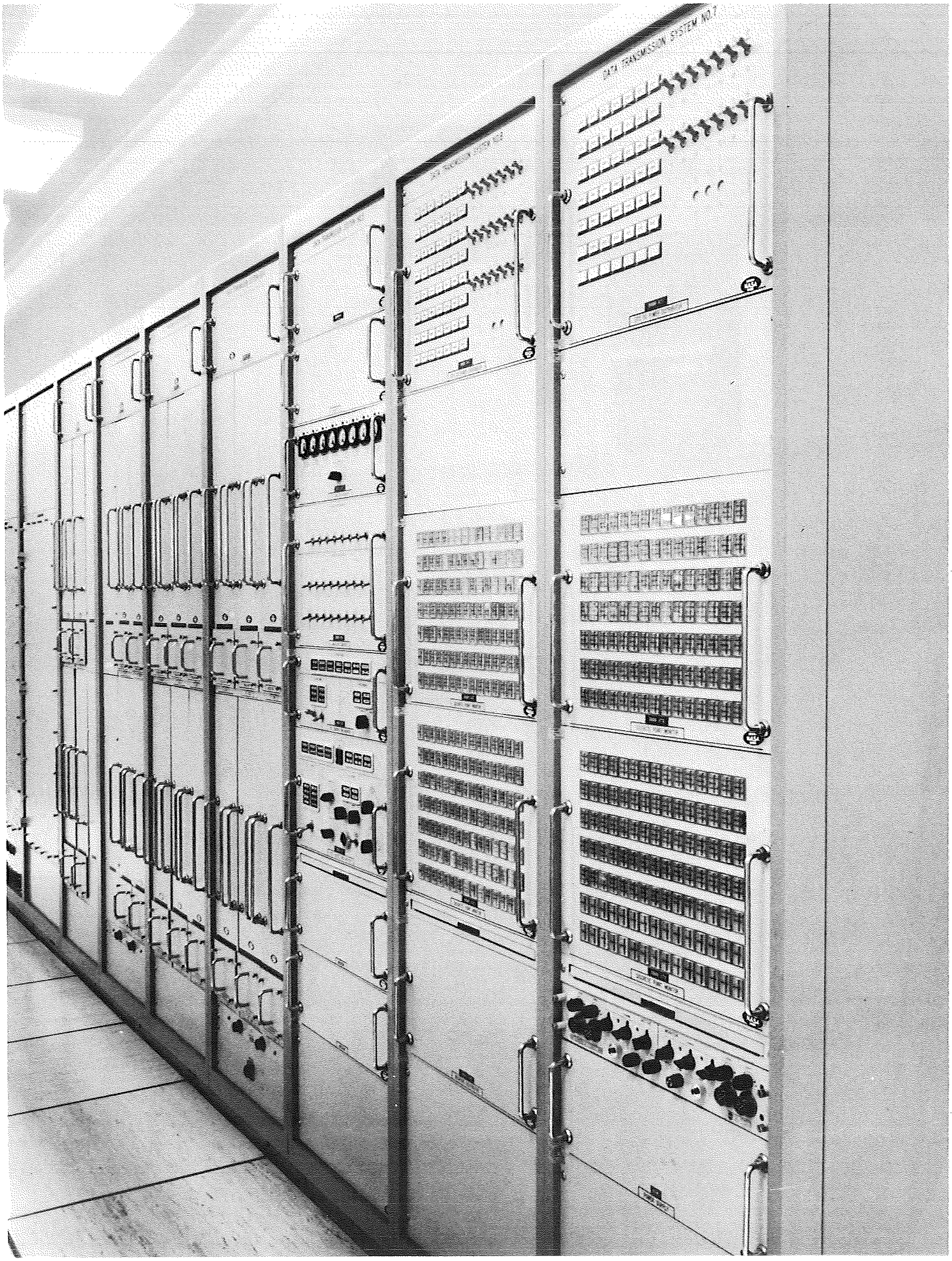

Figure 3-6. Data Transmission System, Launch Control Center

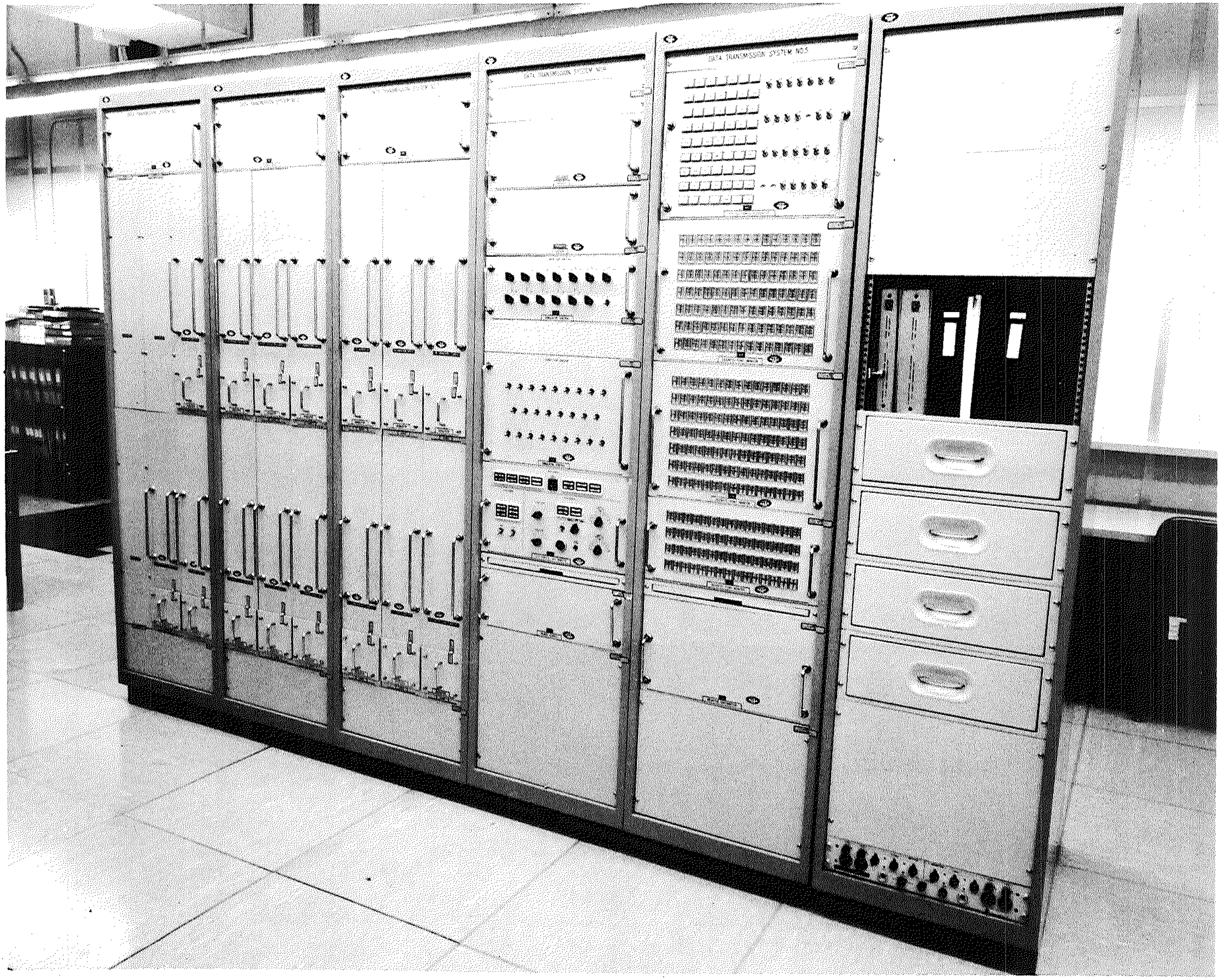

Figure 3-7. Data Transmission System, Pad Terminal Connection Room

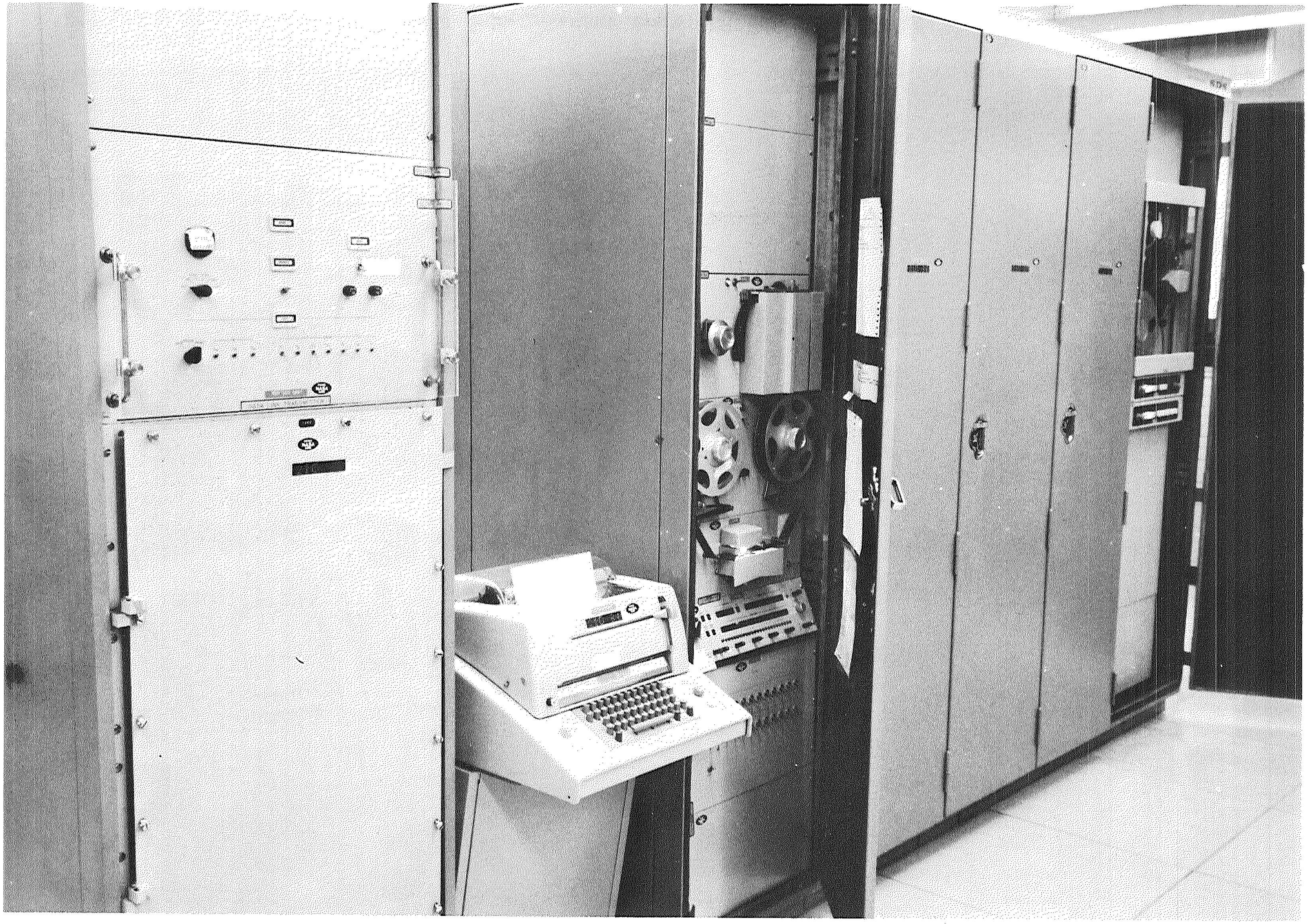

Figure 3-8. Digital Event Evaluator, Pad Terminal Connection Room

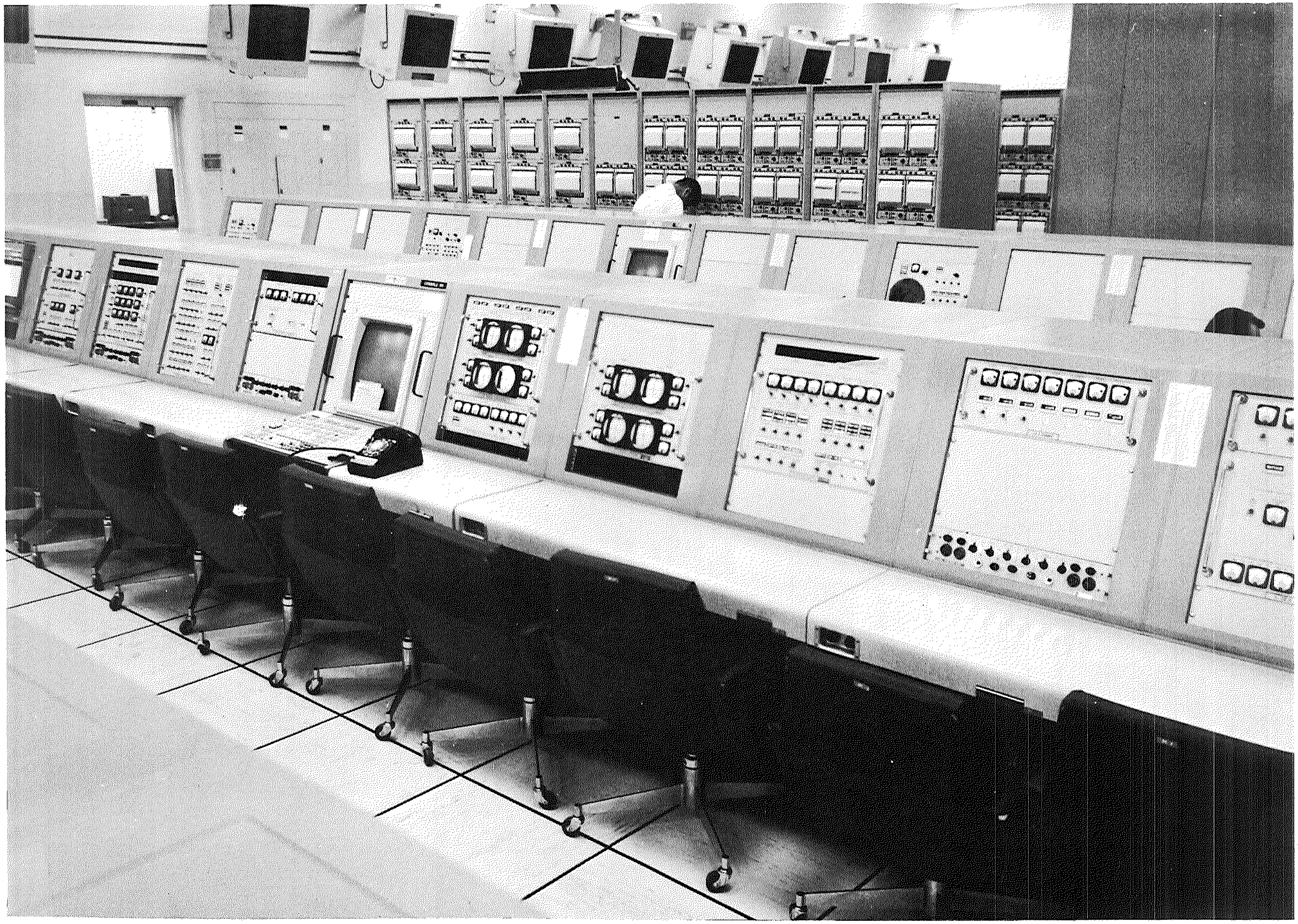

Figure 3-9. Firing Room, Launch Complex 39

The Flight Control Computer Console (Figure 3-10) is typical of monitor and control panels containing control switches and display devices used by the system test engineer during checkout operations.

Each vehicle stage is controlled by separate consoles in the firing room, and consequently the discrete information from a particular stage is displayed at widely separated locations. Stage-oriented digital event readout display panels (Figure 3-11) are utilized to centralize this information and to provide an overall real-time presentation of the checkout status.

Additional discrete monitoring and recording capability is provided by the digital event evaluator (DEE-6) system. This system is divided into three major subsystems (Figure 3-12): the control subsystem, and digital computer subsystem located in the mobile launcher area, and the remote control subsystem located in the launch control center.

The 2160 discrete input lines into the Saturn IB control subsystem are scanned every one millisecond to determine the status of all discrete inputs. (On Saturn V there are 4320 input lines and the scan rate is every two milliseconds.) The control subsystem makes a comparison between the present discrete status and the information ~~is~~ stored in the digital computer system from the previous scan. If the comparison reveals that a discrete change-of-state has occurred, the discrete identification number, new discrete stage, and time is stored in the digital computer subsystem. This information is then recorded on magnetic tape for post data anslysis and readout to peripheral equipment for immediate evaluation.

The output of real-time information is made available to the line printers (Figure 3-13) associated with the remote control subsystem, located in the launch control center. Each launch vehicle stage checkout station is equipped with a separate line printer and only those discretes associated with that stage are made available. A master printer is located at the remote control station and receives discrete information from all stages.

4. Distributors

Hardwire terminal distributors (Figure 3-14) provide the necessary terminal and intermediate test points for trouble isolation in the permanently installed long cable runs between the launch control center and pad areas. When cable configuration changes become necessary, due to equipment additions or deletions dictated by vehicle or payload requirements, only rerouting of the short run cables is required between the terminal and programmable patch distributors.

The rack-mounted programmable patch distributors (Figure 3-15), located in the mobile launcher, are the central distribution point for all control and monitor signals. When configuration changes are necessary, programmable patchboards (Figure 3-16) in a distributor are removed, and the patch-jumper pins are extracted or inserted with special tools to meet the new circuit requirements. When a patchboard is reinstalled, the patch-pins mate with the corresponding paddle-pins on the distributor

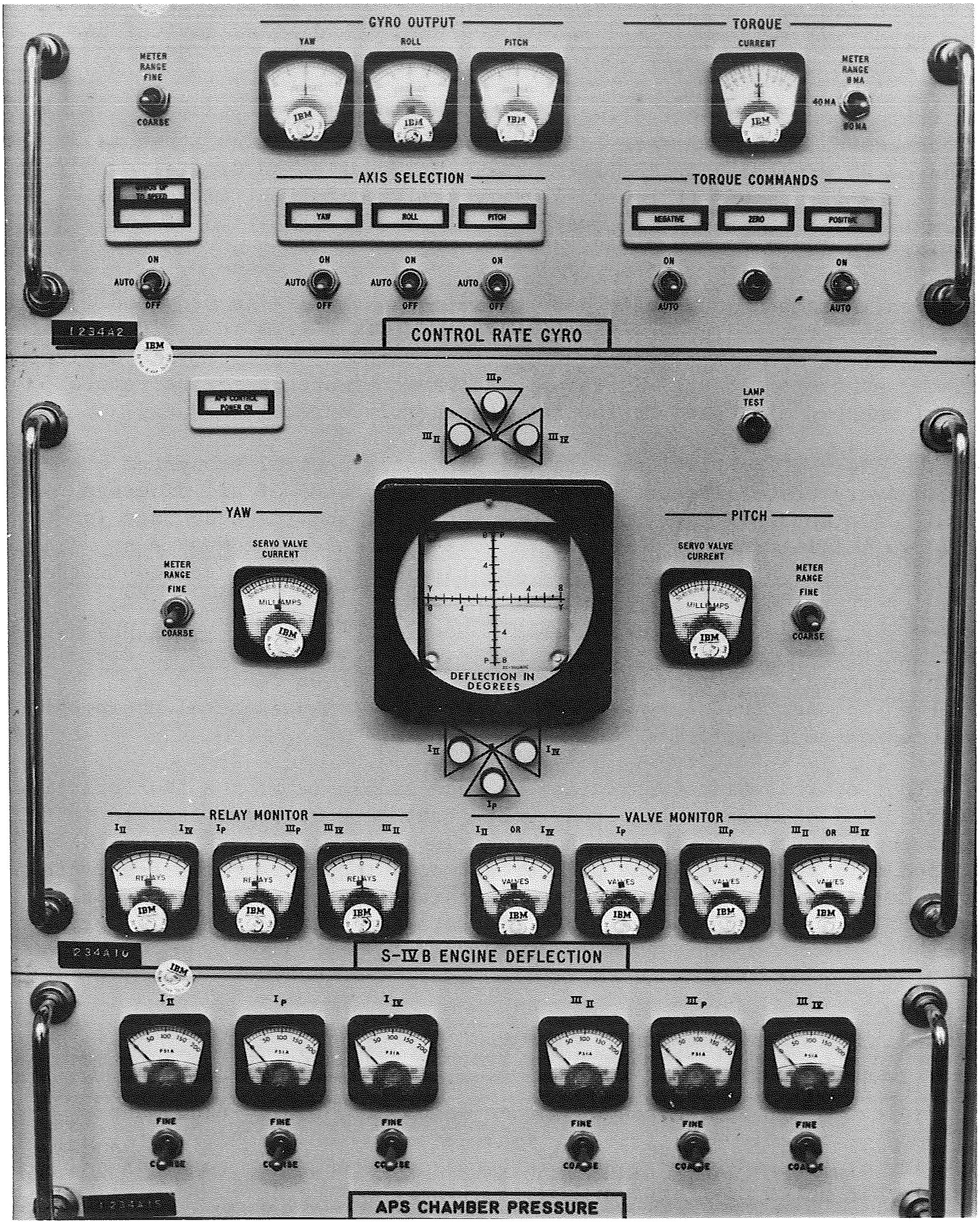

Figure 3-10. Flight Control Computer Console

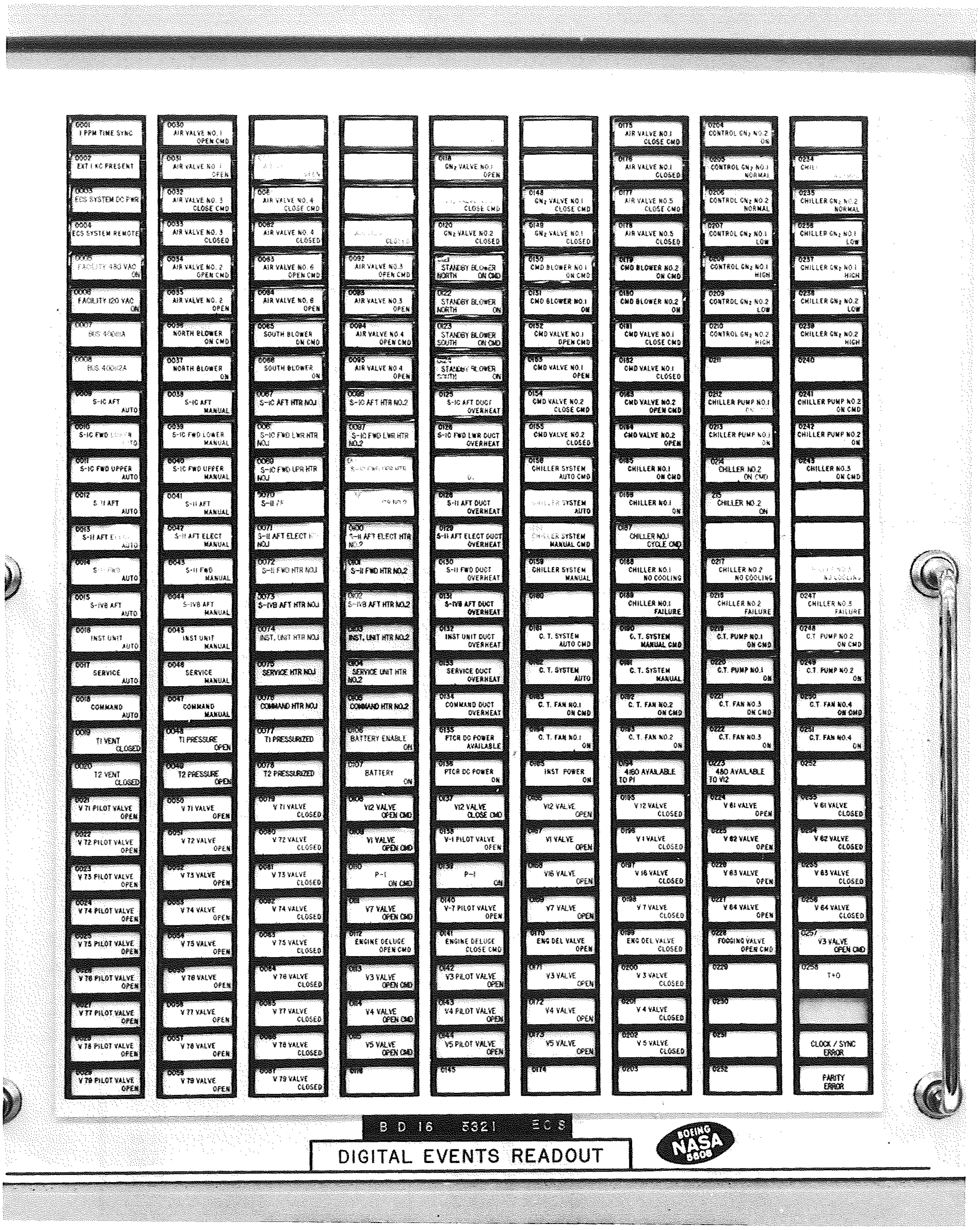

Figure 3-11. Digital Events Readout Display Panel

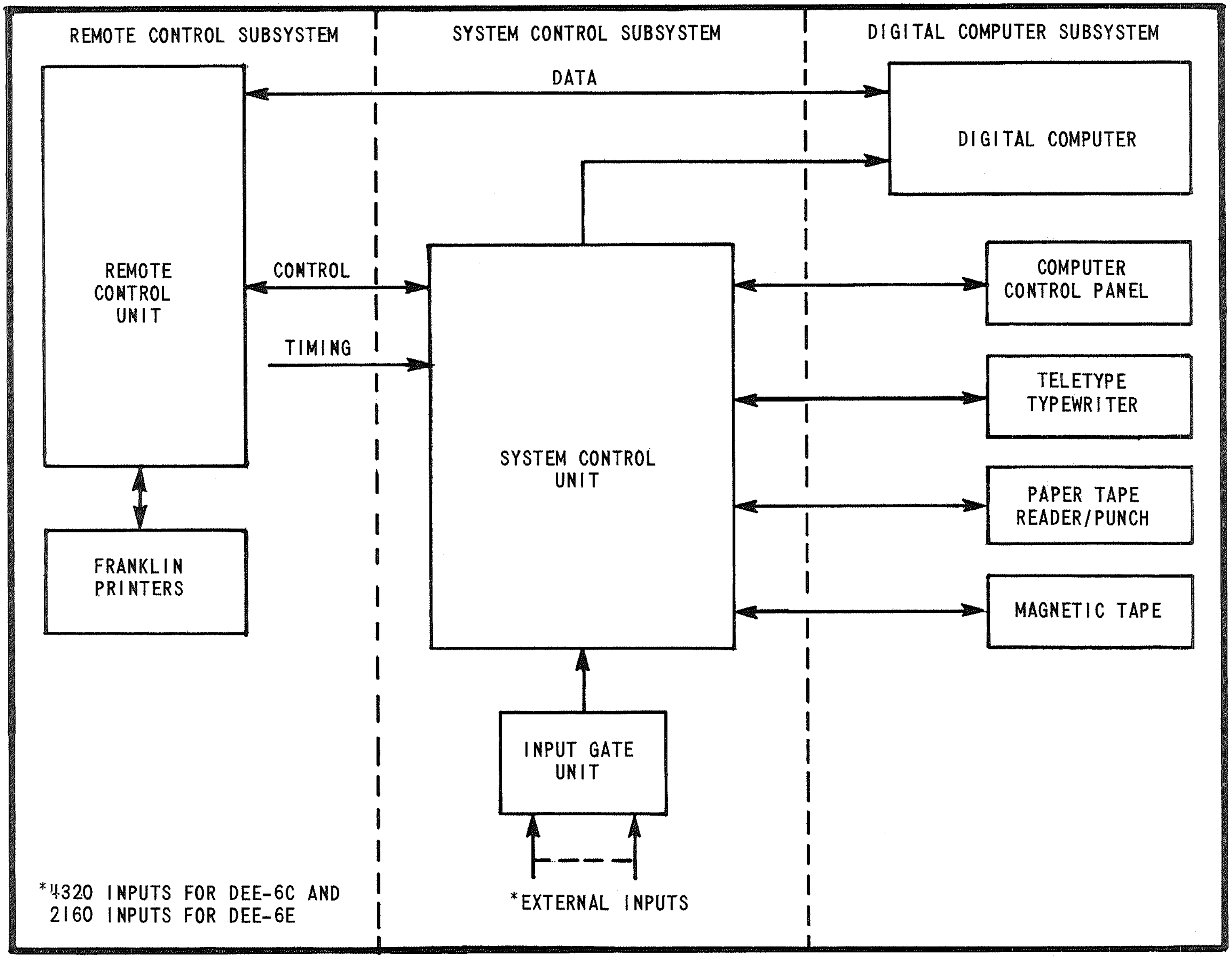

Figure 3-12. Digital Events Evaluator, System Block Diagram

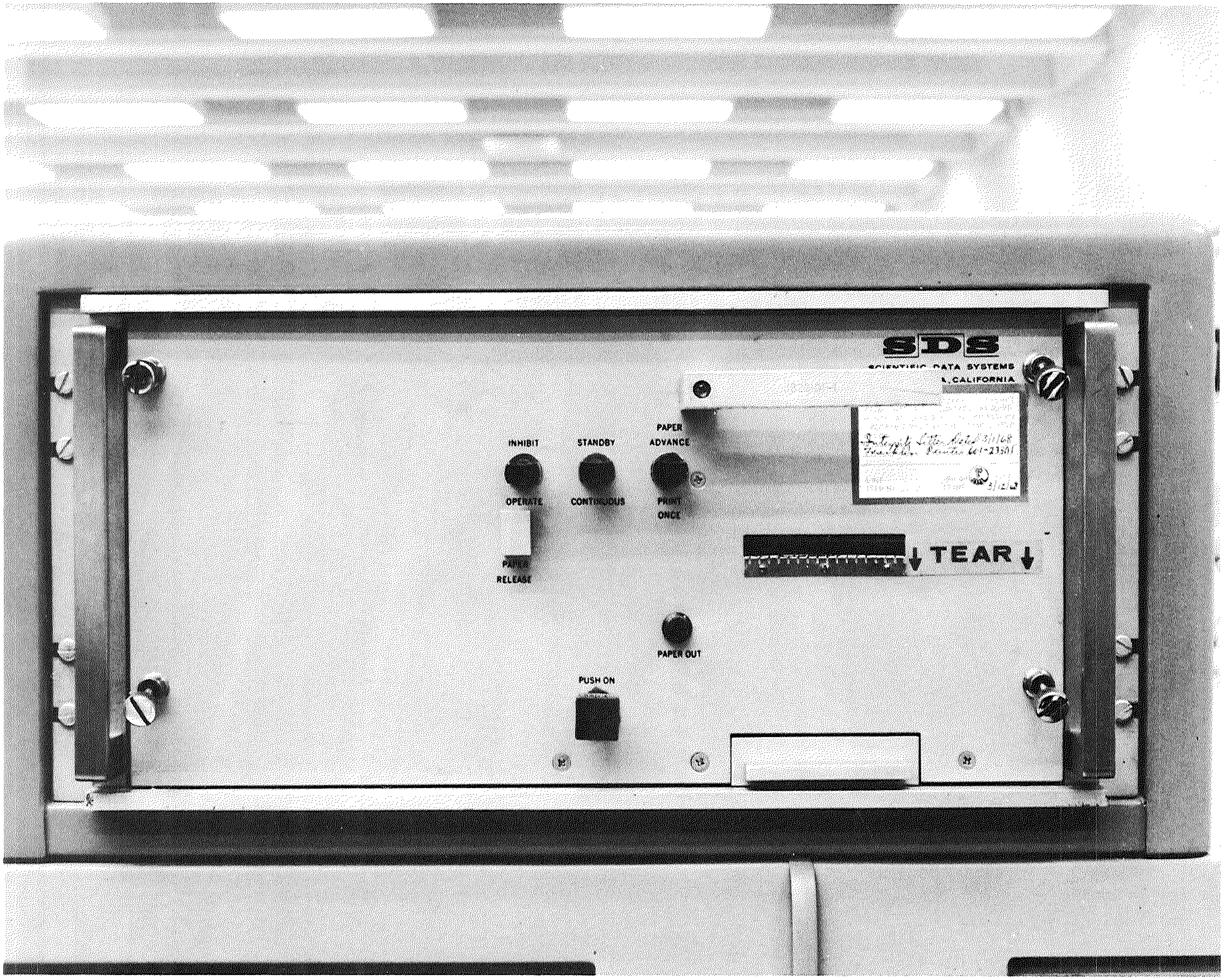

Figure 3-13. High Speed Printer, Front Panel View

Figure 3-14. Terminal Distributor

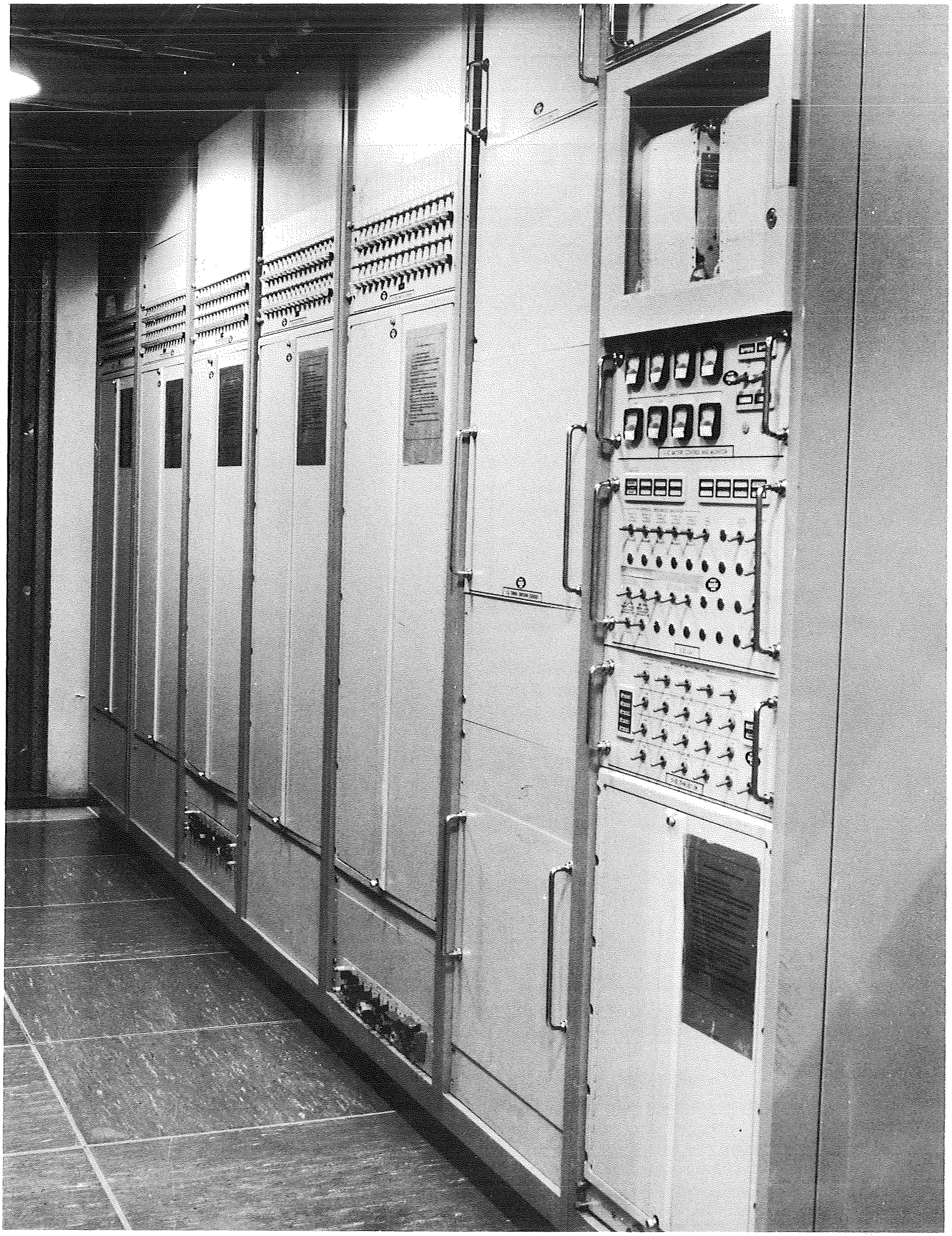

Figure 3-15. Programmable Patch Distributor Racks

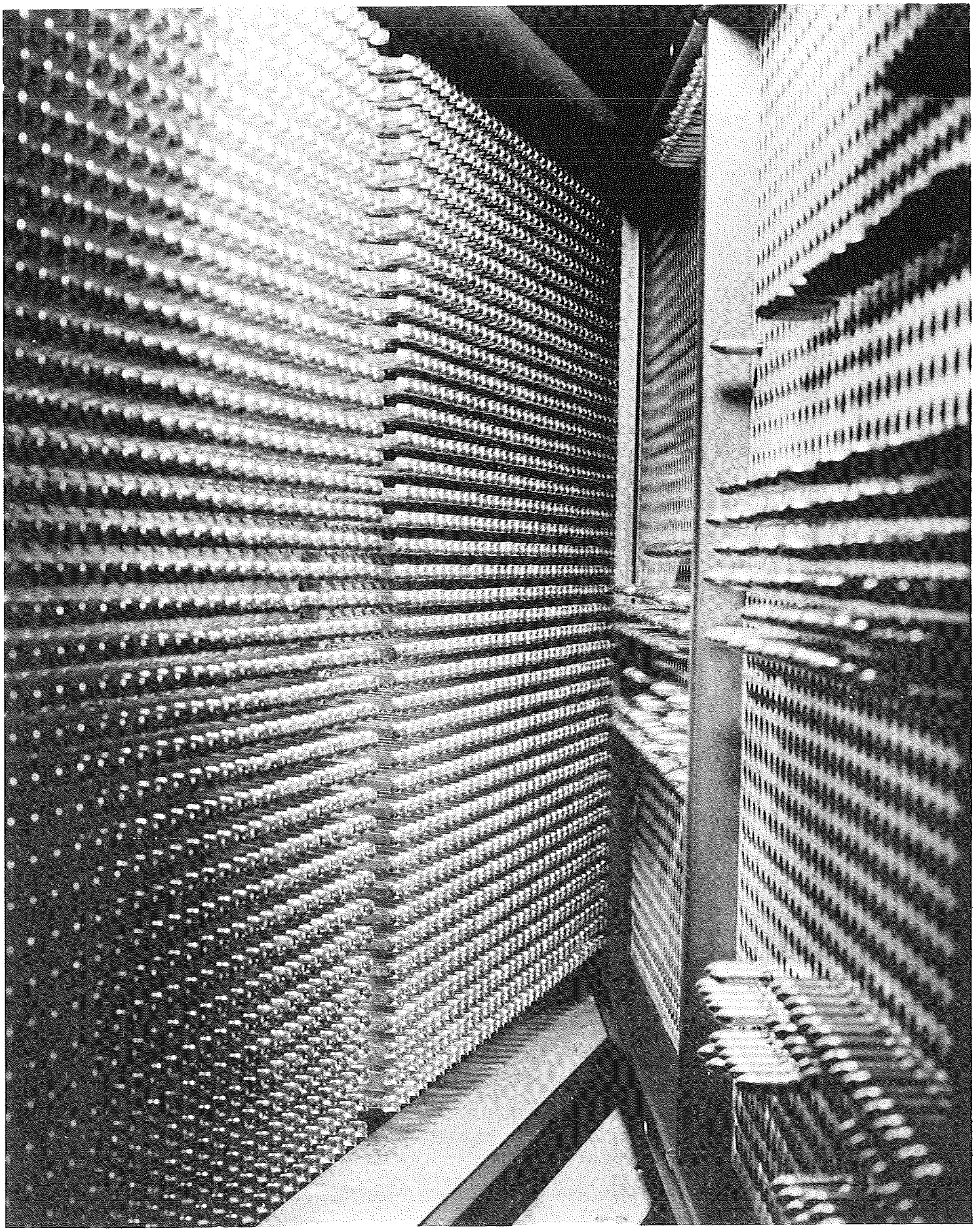

Figure 3-16. Installation of Programmable Patch Board

mainframe and complete the circuit to the conductors in the cables connected at the rear of the patch distributor (Figure 3-17). A typical program distributor patch circuit is shown in Figure 3-18. Test points, located in the front of the distributor, are wired in parallel and provide convenient verification of any junction between circuit components when isolating malfunctions. The distributor connections also receive signals from relay and diode modules and special components panels (Figure 3-19) used to make up the circuit logic and interlocks necessary in controlling checkout operations.

Each relay module is provided with eight crystal-can relays that are connected into the necessary circuitry by patchboard-jumpers in the same manner as the conductors of the interconnecting cables.

Modulator-type circuit boards are mounted on the special components panels. These are used to monitor vehicle stage dc buses, to generate signals used for telemetry calibration, and to time delay relays required for sequencing checkout operations. Jacks are provided to jumper special functions during testing operations.

5. Signal Conditioning

Signal conditioning equipment (Figure 3-20) provides the necessary interface between the electrical control and distribution system and the Saturn ground computer complex. Input discretes to the computer are conditioned to suppress any negative excursions and to eliminate double actuation due to switch or relay contact. The discrete output conditioning consists of relay and relay-driver circuitry. A common dc bus provides power for all driver circuits. The computer discrete output equipment establishes the ground return when any discrete-out is to be issued. The contact voltage for the discrete output relays is supplied by the particular vehicle stage power system associated with that particular discrete output, and provides the safeguard that allows the computer system to support any given stage operations without the possibility of any discretes issued affecting a stage that may be unmanned.

6. Countdown Clock

The countdown clock system (Figures 3-21 and 3-22) supplies Greenwich mean-time to the Saturn ground computer complex for time correlation of display information. The clock system also supplies countdown time to the digital events evaluator and countdown clock readouts. The input signals at the launch control center are obtained from the Air Force Eastern Test Range timing system and are in the form of one pulse-per-second and Greenwich mean-time coded pulses. Synchronization is accomplished by presetting a Greenwich mean-time into the control section of the clock system. When the Greenwich time signal supplied from the range equals the preset time, a synchronization pulse is generated to gate a 2000 cycle Greenwich mean-time, gray-coded, update signal to the clock circuitry for output to the launch control center computer. The Greenwich mean-time update signal is also encoded and transmitted to the pad area where it is decoded and supplied to the pad area computer and digital events evaluator.

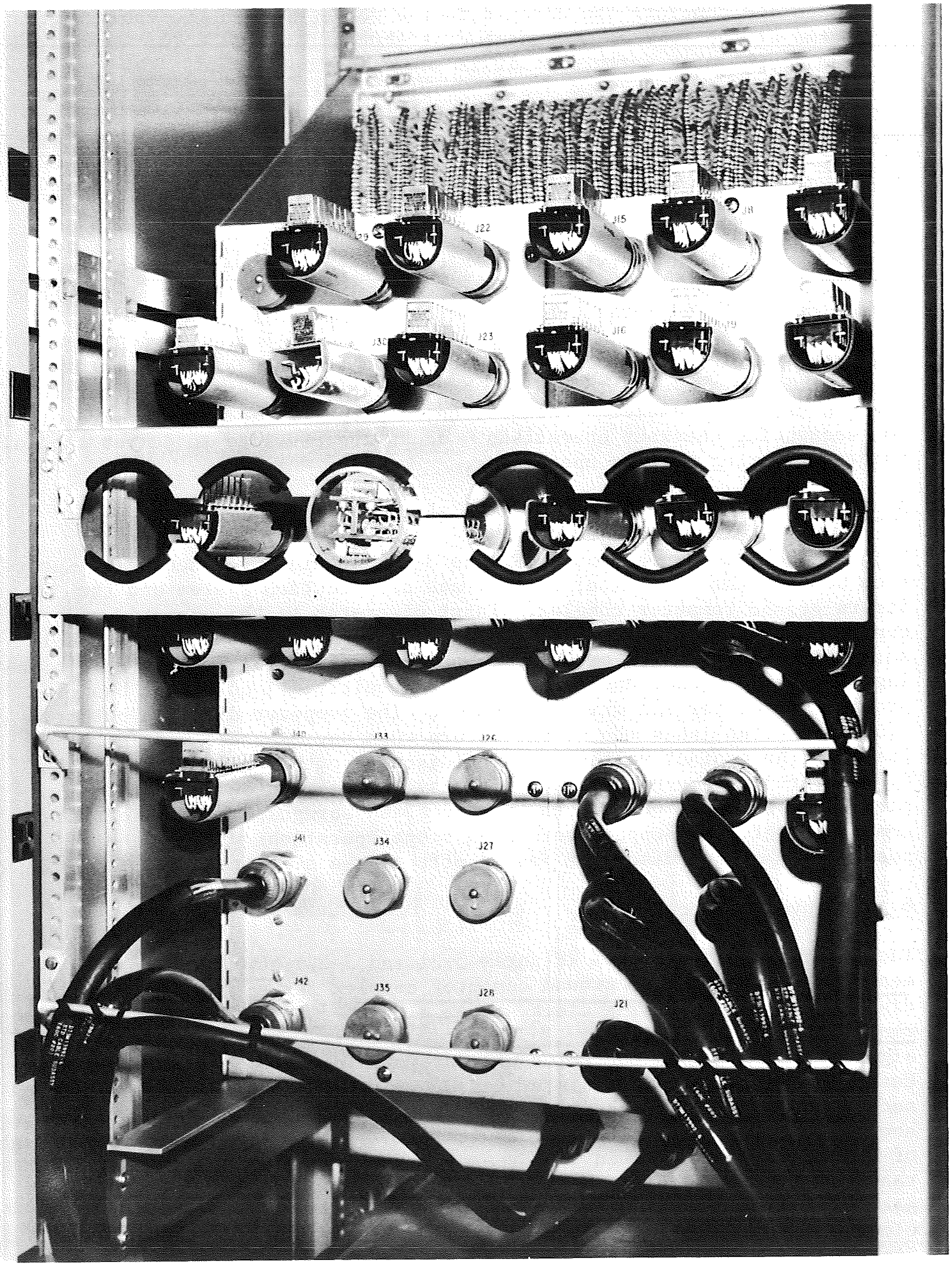

Figure 3-17. Patch Distributor, Rear View

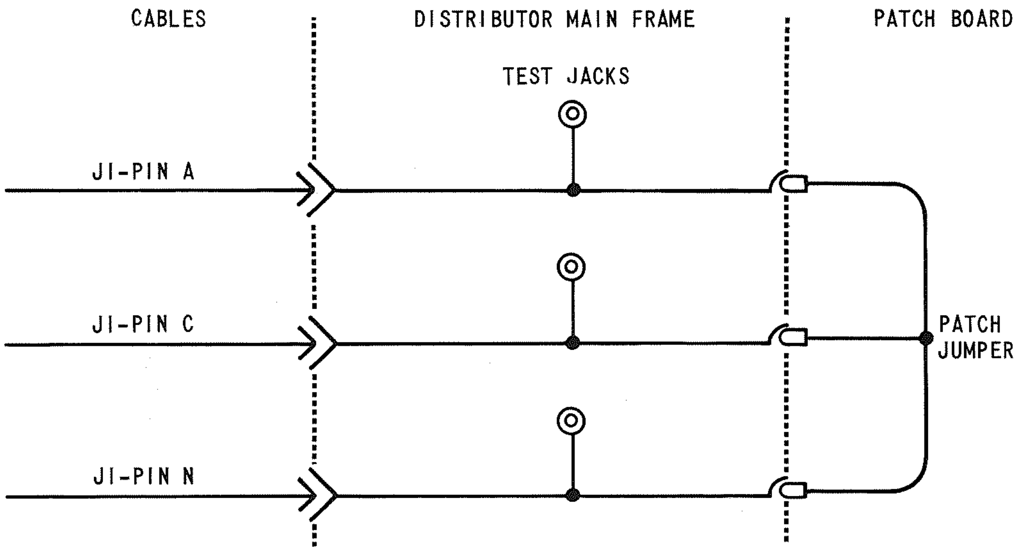

Figure 3-18. Typical Program Distributor Patch Circuit

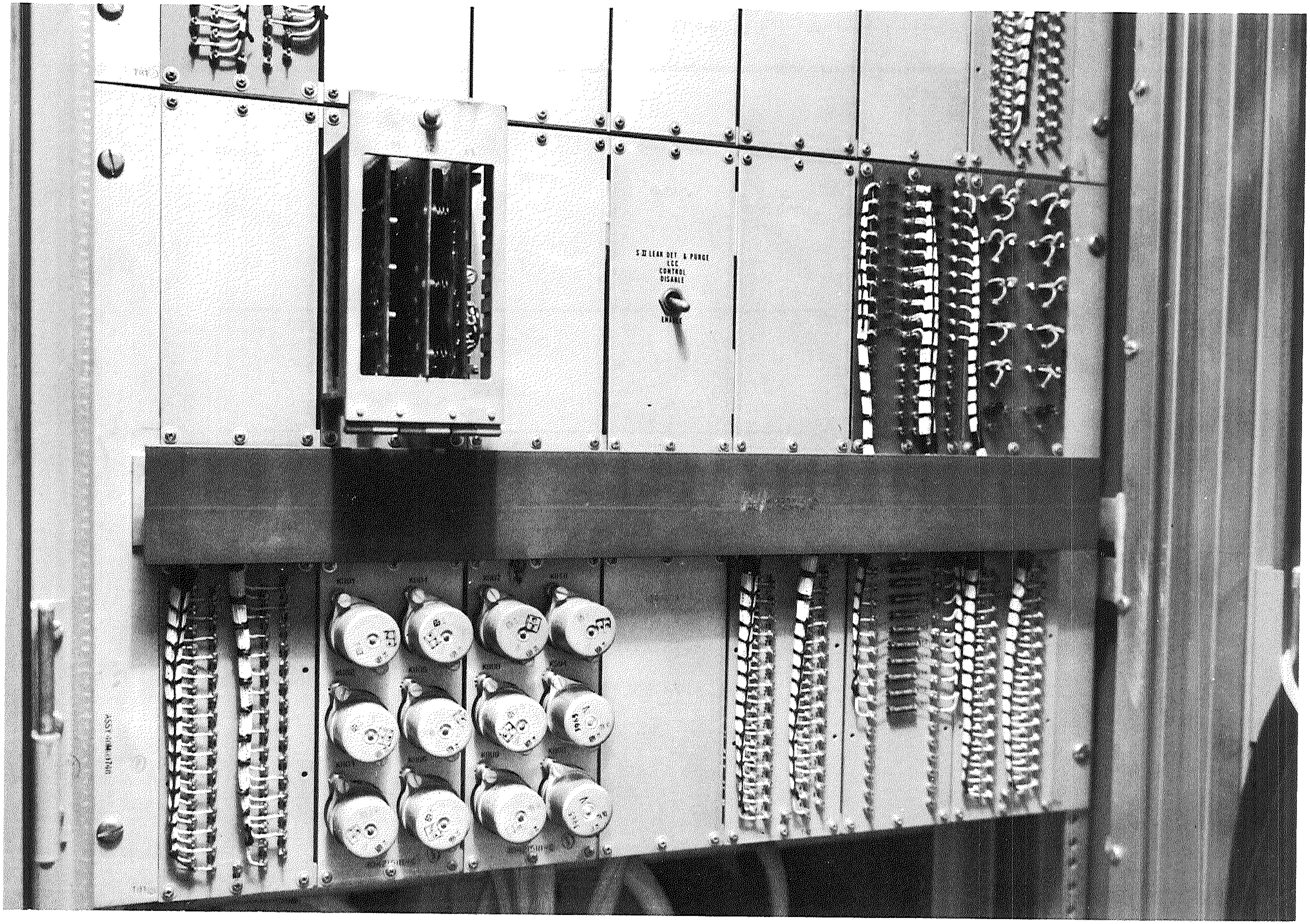

Figure 3-19. Special Components Panel

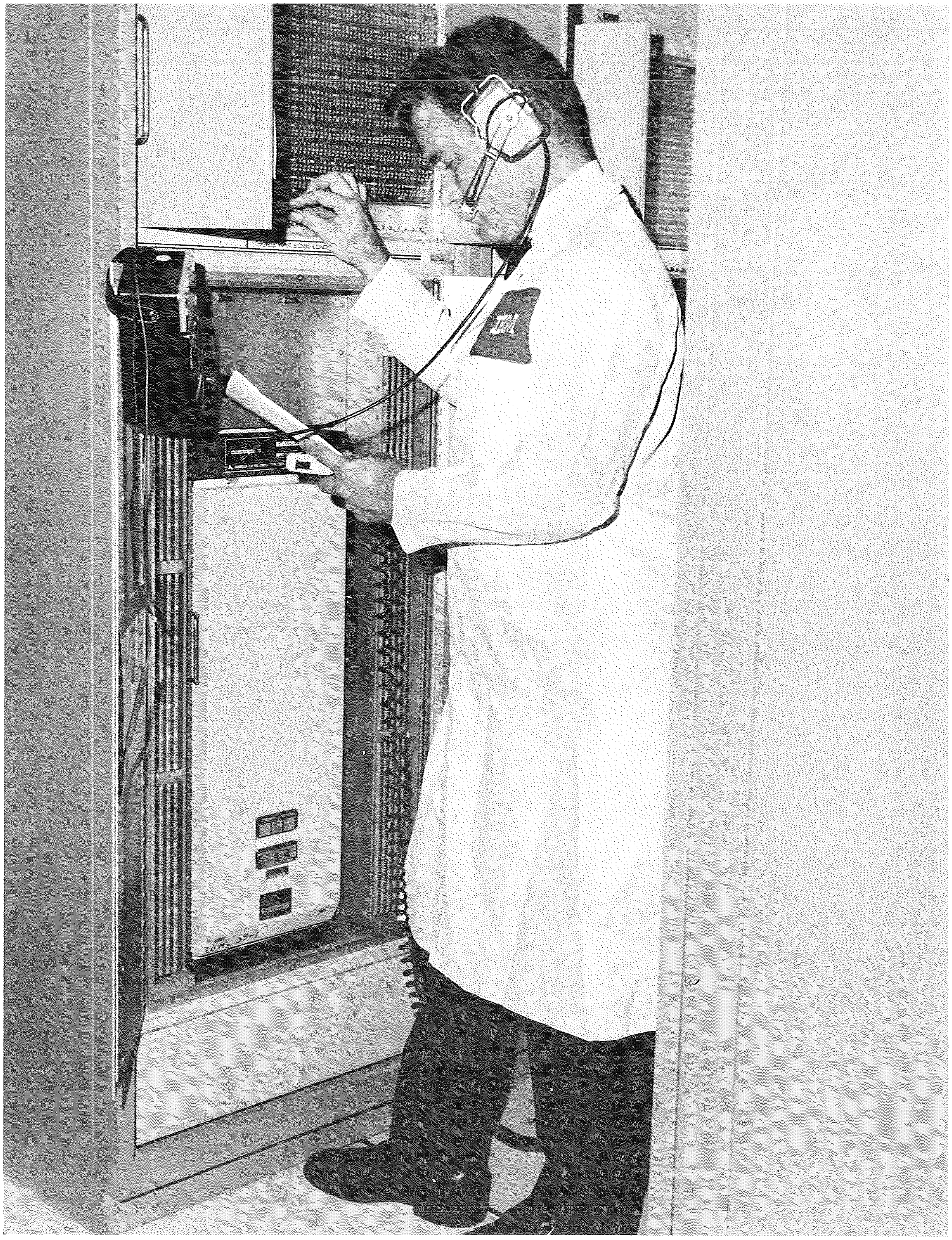

Figure 3-20. Computer Signal Conditioning

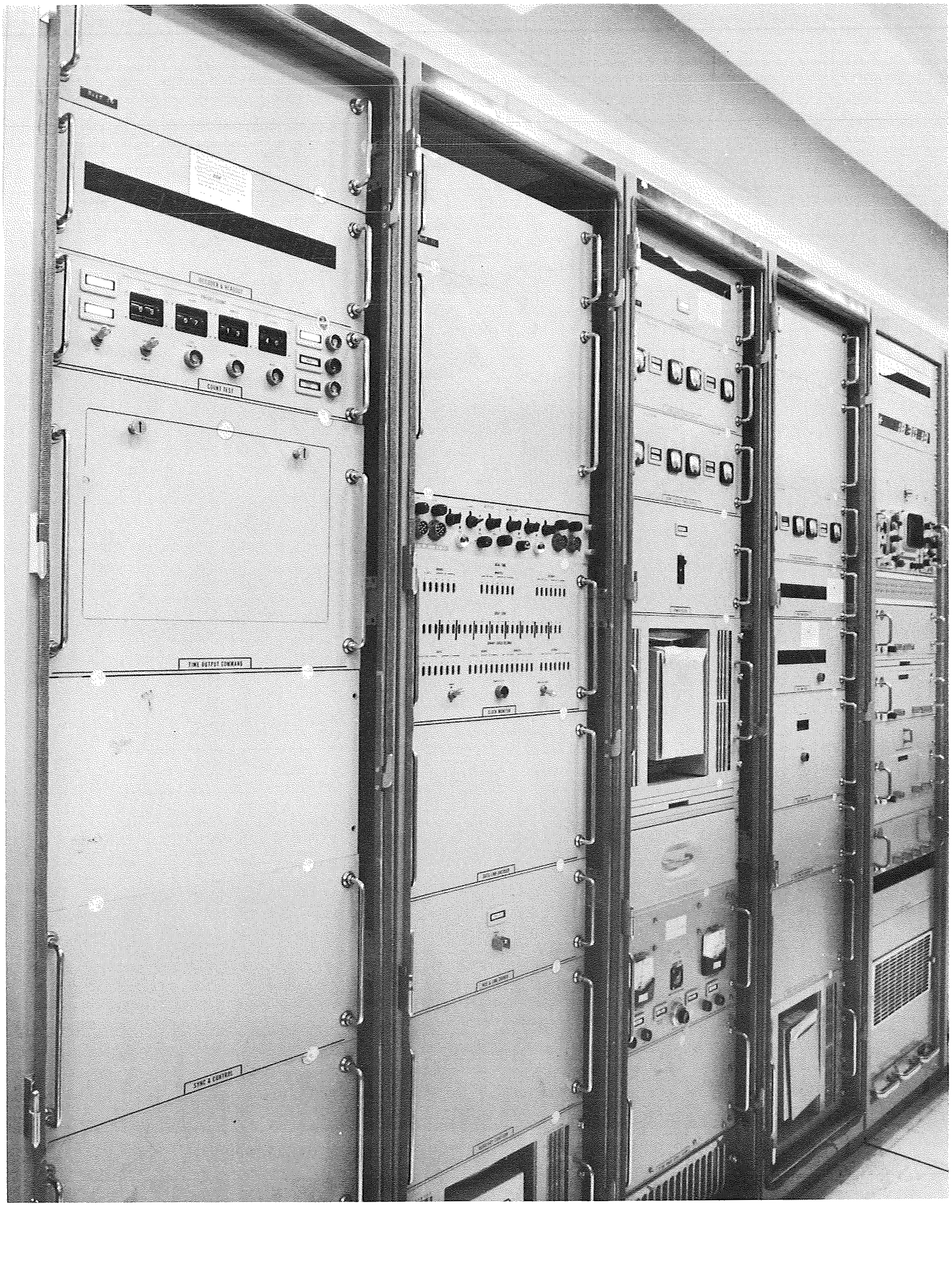

Figure 3-21. Countdown Clock, Launch Control Center

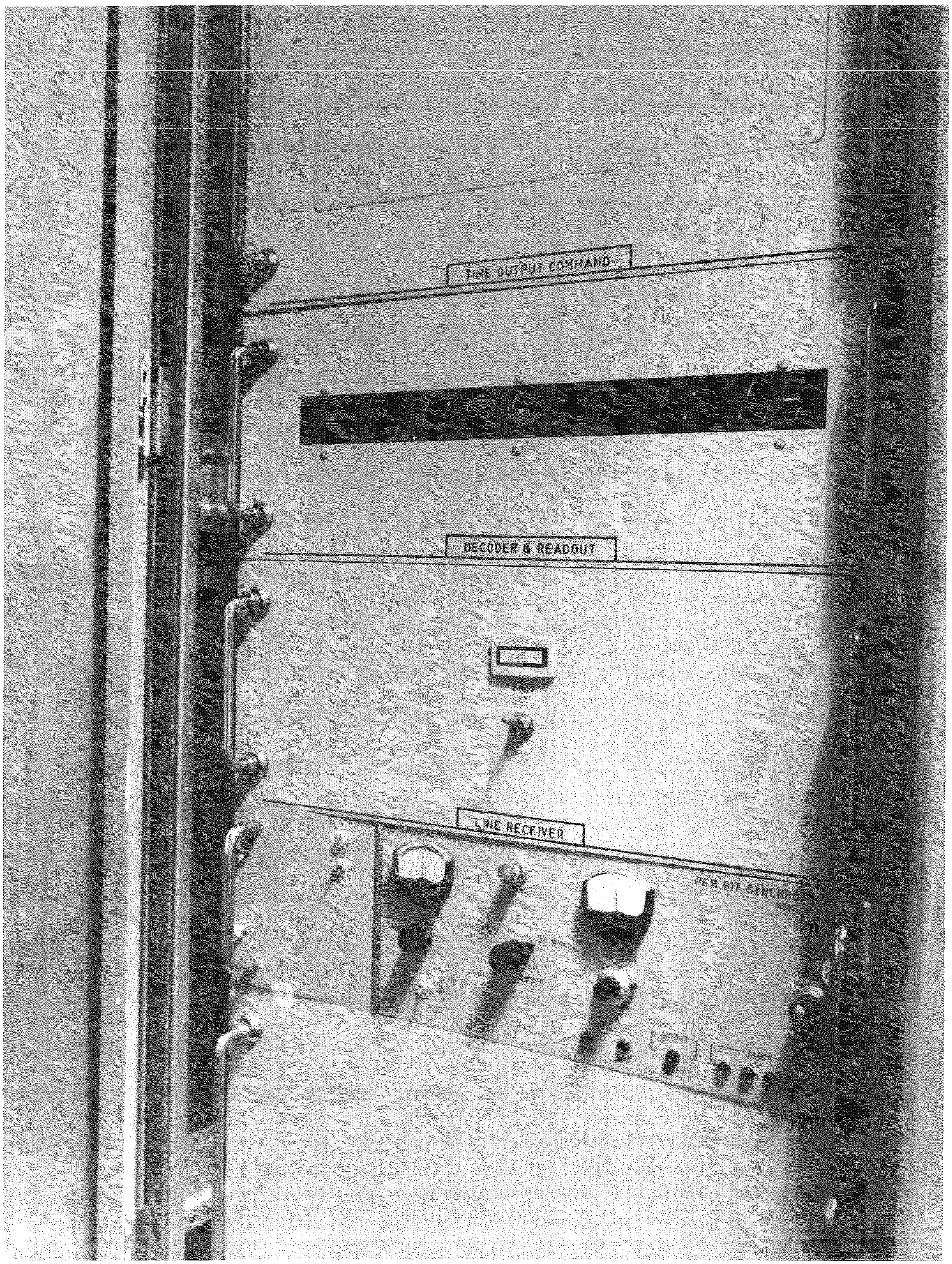

Figure 3-22. Countdown Clock, Mobile Launcher

The one-pulse-per-second signal is used by the terminal launch countdown sequencer for time sequencing vehicle functions during the terminal portion of the launch countdown.

7. Overall Test Room

During some testing operations, certain vehicle components cannot safely be actuated, although feedbacks from these components may be necessary to allow circuit interlocks for completion of the test in progress. Overall test rooms (Figure 3-23) are located in the service structure on launch complexes 34 and 37, and in the mobile launcher on launch complex 39. These rooms are equipped to simulate the actuator functions. In general, the simulation circuits are substituted at the end-item by specially built test cables, and receive the stimuli and provide the necessary feedbacks normally provided by the substituted components. In this manner, the entire circuitry, except for the hazardous component, is functionally verified. Examples of these components are propellant tank pressurization monitor switches, ordnance items, engine thrust OK switches and vehicle flight batteries. Visual monitoring and strip chart recorders are also provided in the overall test rooms.

8. Mechanical

In the vehicle mechanical systems, much of the testing and preparation for launch is performed at the launch pad area by use of portable and locally situated test consoles. The engine servicing equipment and console (Figure 3-24) is used on launch complex 39 to supply a water and ethylene-glycol mixture to the engine cooling jackets on the F-1 engines of the Saturn V first stage. The console provides the power required to drive the supply pump, the control for operation of the system valves, and the indications to determine when the filling operations are complete. Both manual and automatic modes of operation are available as well as remote operation from the launch control center. Mode switching is accomplished by controls on the local console.

C. COMPUTER COMPLEX

1. General

The Saturn V Ground Computer System (Figure 3-25) comprises two computer systems one of which is located in the LCC, and the other in the mobile launcher.

The computer systems, linked together with a data transmission system, consist of specially built interface equipment plus conventional computer elements. Each computer has eight individual memory elements of 4096 words, with additional storage of 32,000 words in each computer provided by a drum system. Seven buffer data channels move data in and out of the memory elements. Each of the data channels has been designed to interface the memory system with specific input - output areas. The data channels associated with the discrete input system continuously scan the input discretes and automatically write the status of these discretes in memory blocks in predetermined locations. These data channels also alert

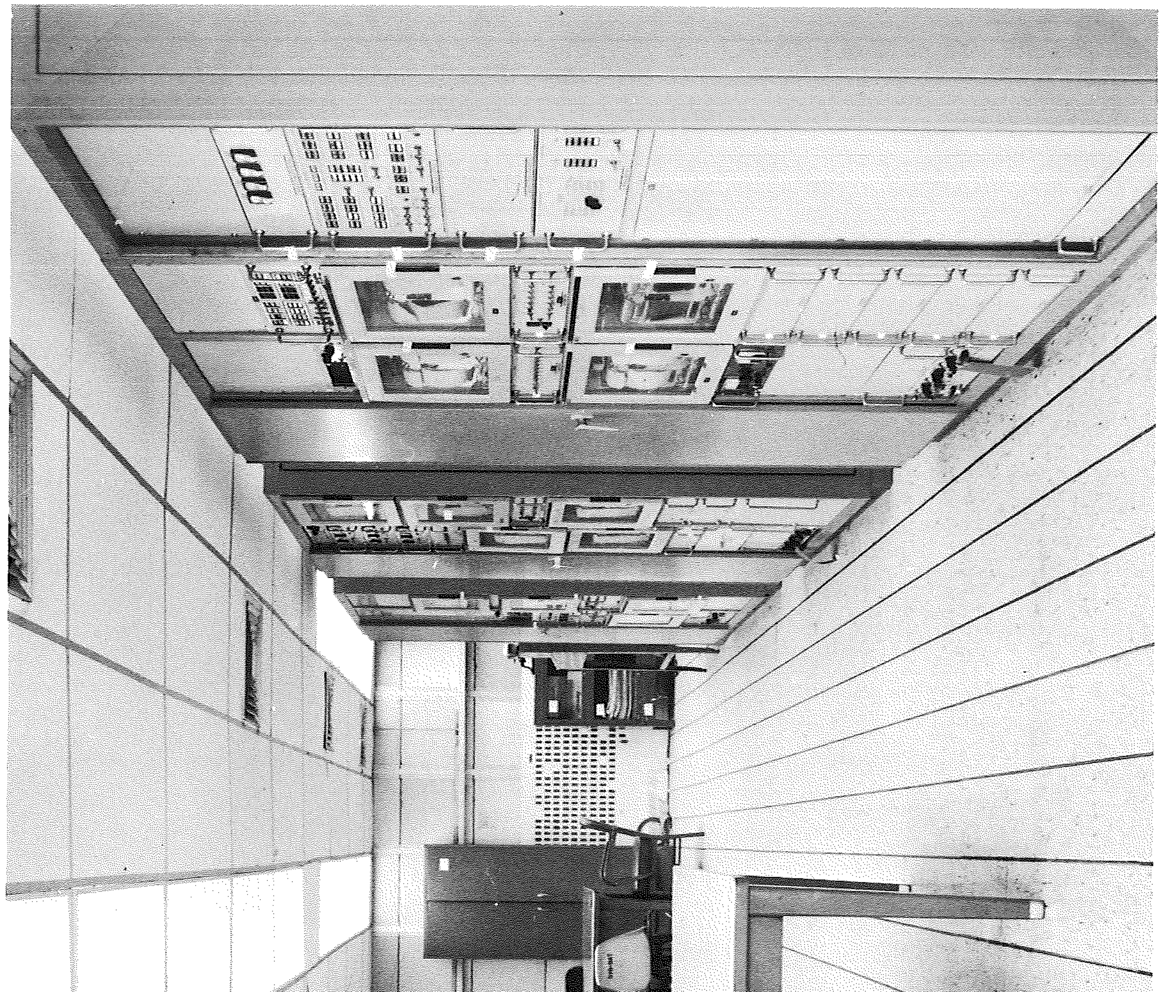

Figure 3-23. Overall Test Room

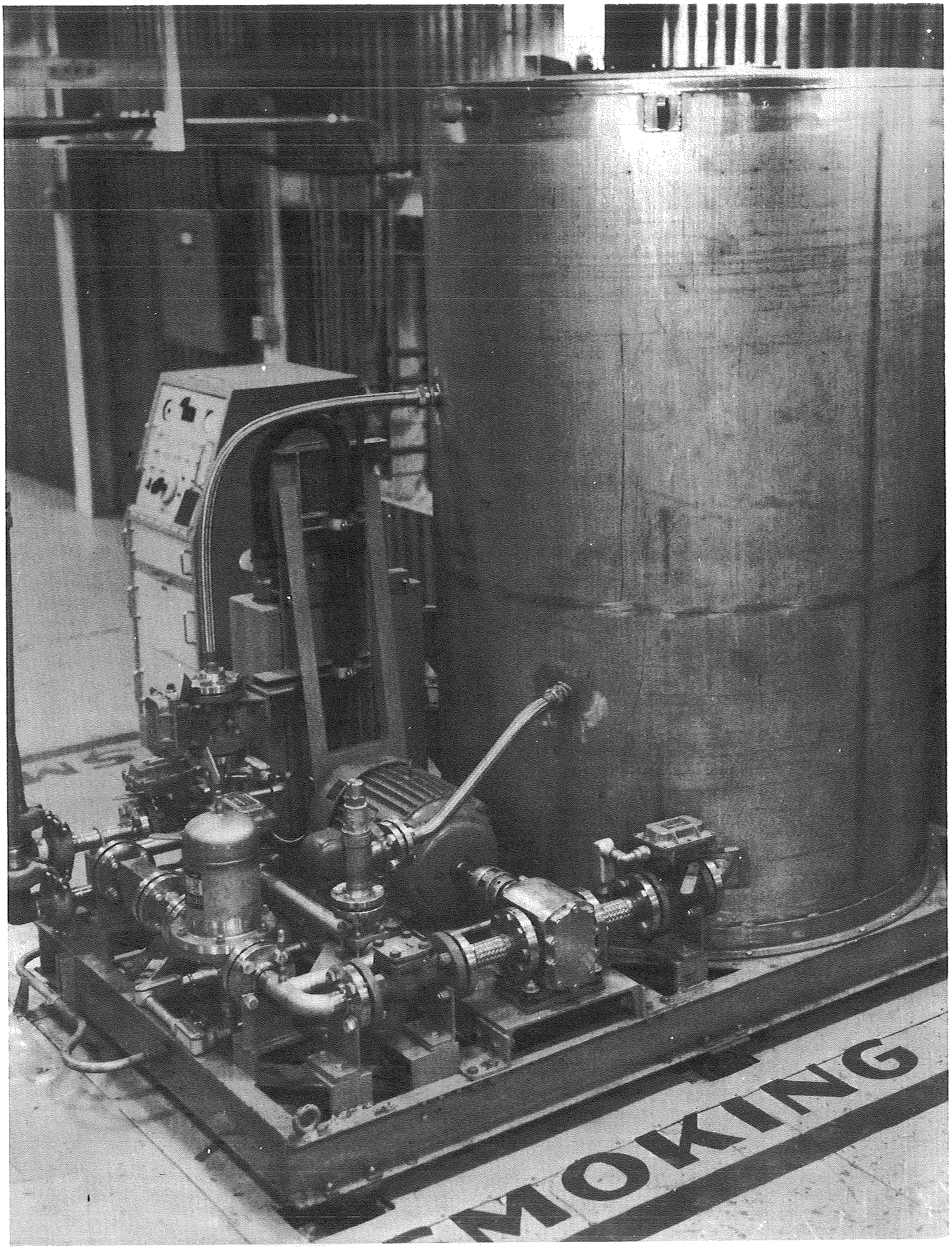

Figure 3-24. Engine Servicing Equipment and Console

the control logic portion of the system through priority interrupt circuitry when they detect a change in input status. The control portion of the system is then free to operate on any given problem without having to interrogate the discrete input channel except when it is alerted. A similar method is employed with all data channels to allow all elements of the system to operate as independently as possible. The data channel operations are totally independent of the computer cycle operations with the exception of the setup and termination operation.

Information passed to the data link system is stored and reformatted in the data link terminal for transmission to the corresponding data link terminal at the other computer system. A data block transmission is accomplished utilizing horizontal and vertical parity checking to virtually eliminate undetected errors in transmission. Redundant data link systems have been provided.

The discrete output system is triple-modular-redundant with majority voting on each of the output channels. Independent power supplies are provided for each group of discrete output channels. With this configuration, if the computer fails, the discrete output status is maintained and can be controlled from a manual control panel in the launch control center.

The interface with the digital data acquisition system is accomplished through a memory element in that system so that any given parameter data can be accessed immediately by the computer without having to wait for the normal computer processing. Through this interfacing method the computer has random access to all acquisition system data.

The communication between the Saturn ground computer and the launch vehicle digital computer/data adapter is through the pad area ground computer input-output register and signal conditioning equipment. Data communications between the two asynchronous devices is controlled by priority interrupts.

In the launch control center, a data channel is utilized to interface with the display system. At launch complex 39, the display system processor contains a separate digital computer that receives basic data from the launch control center computer as the result of request by the display operator or a program operating in the computer. This data is then adjusted, formatted, and displayed on a cathode-ray tube.

At launch complex 34 and 37, display system processing is performed by the launch control center computer. The processor formats the display data and passes the graphic and alphanumeric display information through the data channel to the display console. The display console keyboard provides the communication link between the console operator and the launch control center computer.

Two input-output data channels control various peripheral equipment utilized to communicate with the computer and to provide bulk storage for data. Among the devices used are card readers, card punches, high-speed line printers, magnetic tapes, and magnetic drums, all of which operate under the control of the input-output data channels. The card reader is

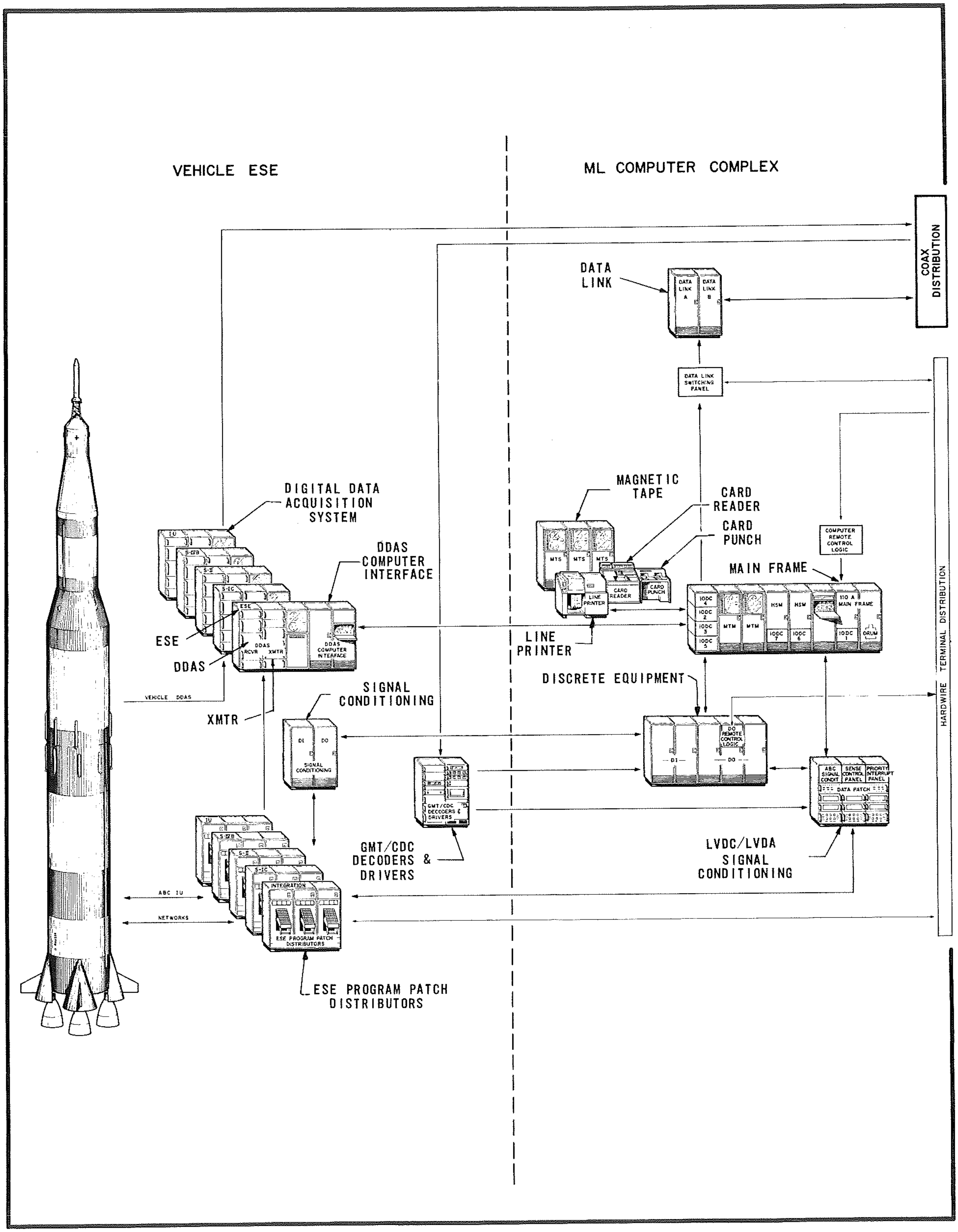

Figure 3-25. Saturn V Ground Computer System, Pictorial Diagram (Sheet 1 of 2)

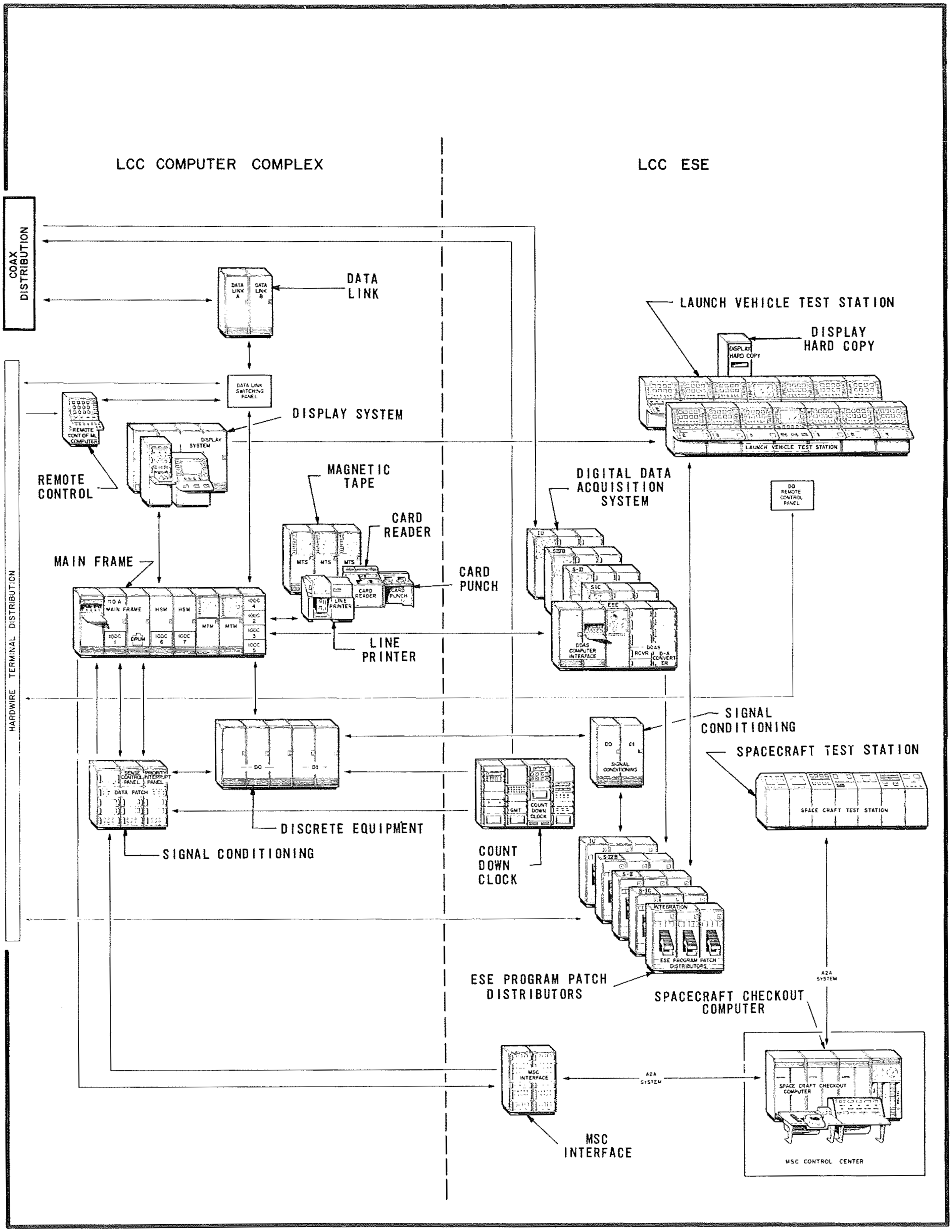

Figure 3-25. Saturn V Ground Computer System, Pictorial Diagram (Sheet 2 of 2)

used mainly for variable program input data and reads up to 800 cards per minute. The card punch is used for off-line program assembly and punches up to 650 cards per minute. The high speed line printer is used to provide a hard copy of program output data and can print 1000 lines per minute. Each computer interfaces with magnetic tape stations that provide storage for programs and an output device for bulk storage of data. The magnetic tapes can read and write at a rate of 15,000 characters per second.

The interface with the spacecraft ACE (Automatic Checkout Equipment) computer is accomplished by use of input-output registers, sense lines, and a priority interrupt system. When the status of the emergency detection system discretes change, the ground computer receives an interrupt. Under program control, the new status can be evaluated and corresponding lamps on the system engineer console can be illuminated by use of discrete outputs. The ground computer also keeps the ACE link in constant operation by returning test messages sent by the ACE/spacecraft computer.

2. Discrete System

The discrete system consists of two main elements; discrete inputs and discrete outputs. The Saturn IB ground computer complex is capable of receiving 1512 28-volt input signals. In the Saturn V system this capability is doubled. The main function of the discrete input section is to encode the 28-volt information into the proper format to be received by the input-output data channel and to provide complete checking of the process.

This section also contains a relative time counter that receives a one-kilocycle input from the countdown clock system. The associated input-output data channel provides the necessary access to the computer memory by building a discrete input status and log history table in the memory. This is a rather unique process and is accomplished as follows:

a. The existing status information is compared with the incoming discrete information. If a difference exists, the contents of the relative timer and the discrete input information are directed to the memory log table. A priority signal is also given, signifying to the computer that a change has been detected.

b. If no change is detected, the process is continued.

c. If an error is detected, the contents of the relative timer and the discretes being scanned are directed to the computer memory. In addition, a priority signal is given.

d. When the relative timer is filled to capacity, and starts to recount, the information is directed to the memory log table along with a priority interrupt signal to the computer.

The discrete output section of the system contains the necessary logic elements consisting of decoders and error detecting devices. In the

Saturn IB system, the decoders allow the computer memory and process logic to issue 1008 discrete output commands. In the Saturn V system, this output capability is doubled. Error detection is provided in both systems. In addition to circuitry that prevents the issuance of more than 24 discrete outputs at one time, the Saturn V discrete output (Figure 3-26) has the following additional features: All elements are triple redundant voter logic elements containing two independent 28-volt redundant power supplies, and encoder logic elements used to determine the status of the discrete outputs generated. This information is available to the computer. This system can also be used independent of the computer through the utilization of a manual control panel located in the launch control center operator station. Switching from computer control to this panel is at the manual control panel. In addition to being able to issue any discrete output, the panel operator can read the status of any discrete output.

3. Display System

The Saturn IB display system consists of a power and logic rack and six display consoles, each of which include a keyboard and a storage type cathode-ray tube. The logic rack provides the necessary conditioning and control elements to allow direct access to the Saturn ground computer memory through the display input-output data channel. The Saturn ground computer processing must include all the necessary formatting for alphanumeric and vector displays presented on the display consoles.

The Saturn V display system (Figure 3-27) is part of the Saturn ground computer complex. It contains six major elements: the central logic and refresh-memory, a control processing digital computer, up to twenty display consoles, television input and output equipment, and slide and hard copy equipment.

The control and logic refresh-memory section contains the necessary distribution to the display data processor, video switching, and digital switching. Digital switching controls the refresh-memory cycle, complete or selective updating of the refresh-memory, and the use of any memory bank by any display console. Video switching controls hard copy, television transmission, slides, and closed circuit television. The display consoles feature keyboard control, ability to display slide information, operational television information, alphanumeric and vector information, and alphanumeric and vector overlayed with slides. The television transmission equipment is capable of transmitting the alphanumeric and vector information. The hard copy equipment is a film processing-to-paper system and is capable of reproducing the alphanumeric and vector information, and alphanumeric and vector overlayed with slides.

The digital computer processor, as a result of a request by the operator or a program operating the Saturn ground computer complex, receives basic data from the central system. This data is adjusted, formatted, and passed on to the correct refresh-memory where it is switched to the correct console, alphanumeric and vector display generator system, and displayed on the cathode-ray tube. The video system can show slides or closed circuit television from any one of ten inputs of a selected channel.

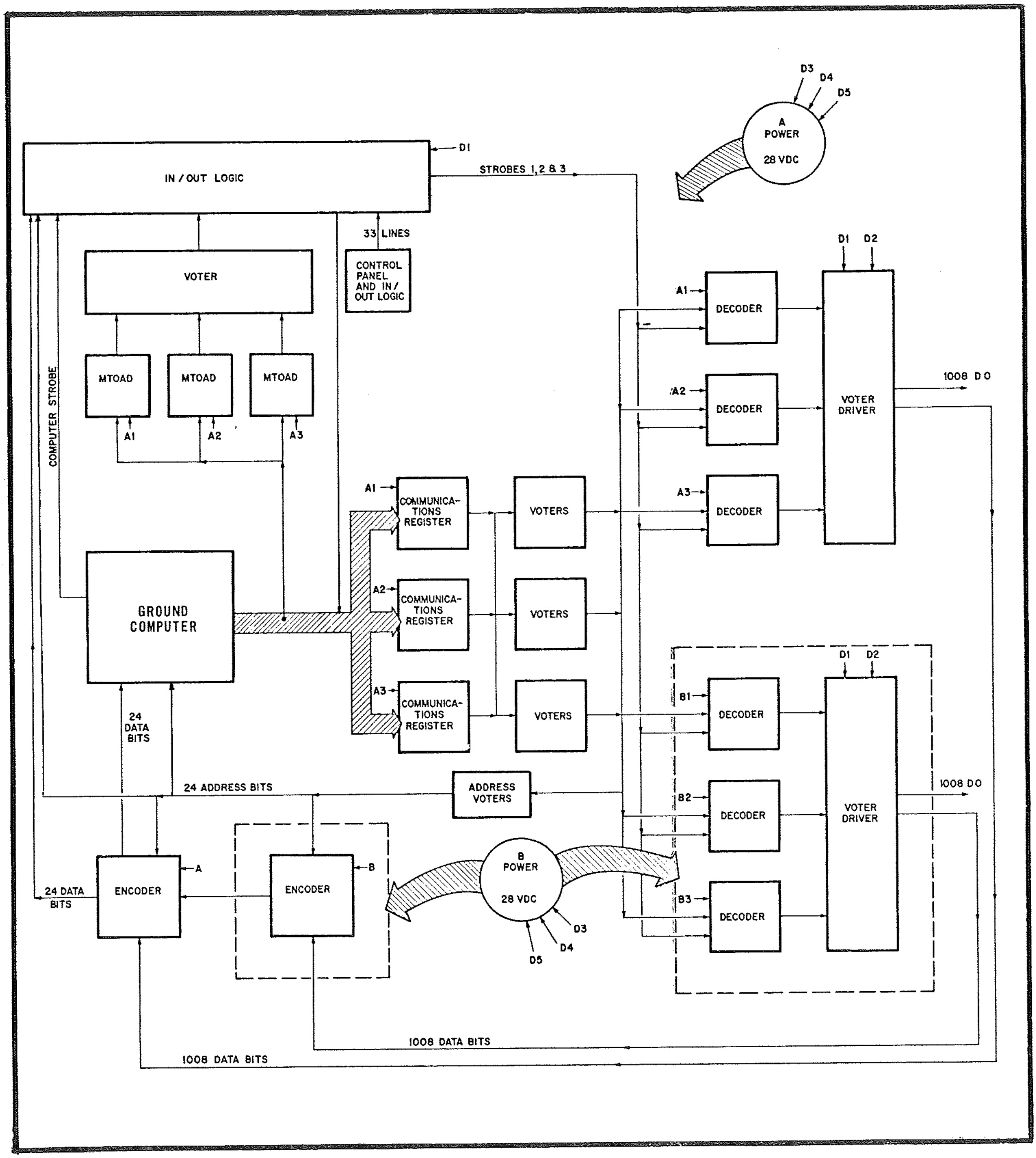

Figure 3-26. Discrete Output, Flow Diagram

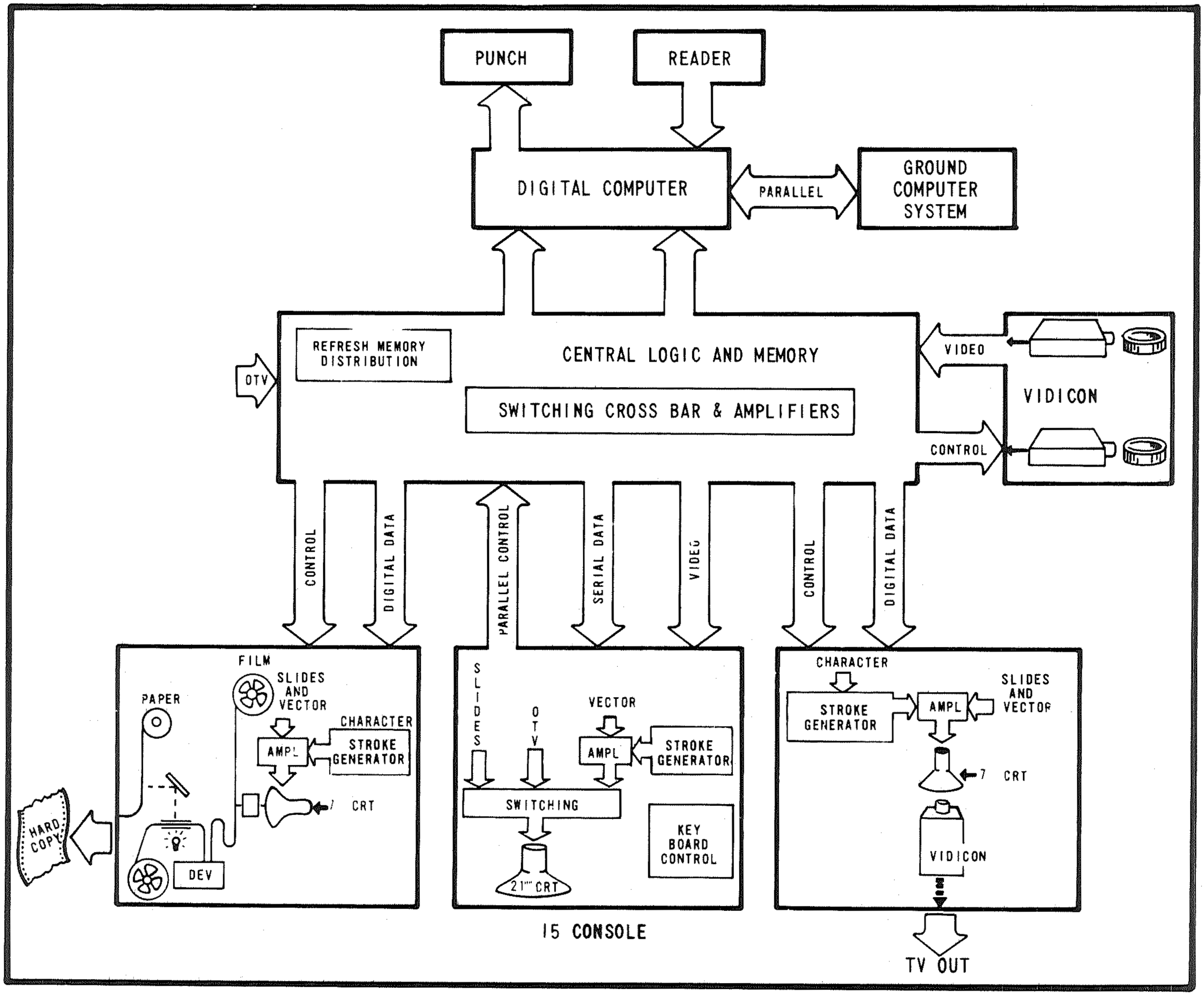

Figure 3-27. Saturn V Display System, Flow Diagram

A full array of controls is available to the operator at each console. Each console can request and read the refresh-memory, driving any other console; similarly, any console can request and receive any data so that the loss of the console system will only require an operator to share an adjoining system. Each console is equipped with a keyboard and light-pin controls for controlling the display system and communications with the control consoles.

4. Operating Program

Programming efforts with the launch control system was difficult because much of the programming was in series with final design release. This required an approach in which programming of a universal application is performed as much as possible. Then, as special programming oriented toward unique tasks became available, it was added to the basic general usage programs to complete the package.

Two types of programs are used in the Saturn ground computer complex. These are the operating system programs and test programs.

a. Operating System Programs

The basic operating system program provides the Saturn ground computer complex with the ability to fulfill its requirements to the control and checkout systems, mainly allowing the system to be used for manual operations. In addition, it contains elements which are prerequisites for automation checkout, but does not test or monitor anything in the vehicle or on the ground automatically. It is part of the system that replaces hardwire by computer programs and a digital data link, therefore providing manual operations with a more advanced state-of-the-art technique. The operating system program operates continuously and seeks alternate paths whenever a failure is detected. When no further paths are available the appropriate message is displayed, requiring manual intervention. Differences exist between the Saturn V and Saturn IB operating system programs:

1) The discrete executive at the Saturn V complex processes all pad and vehicle discrete information prior to transmittal to the launch control center computer. The Saturn IB system transmits the entire vehicle discrete status approximately every one-half second to the launch control center computer.

2) Test program execution is in the Saturn IB pad computer and in the Saturn V launch control center computer. In addition, a function executer program is provided in the Saturn V pad computer.

Complementary parts of the operating system programs are contained in both the Saturn IB and Saturn V equipment. The operating programs are considered as design-furnished equipment. In general, each system program can be considered to be in ten components; launch control center storage allocation (Figure 3-28) and pad program storage allocation (Figure 3-29). These are as follows: The input/

output control system, display data link executive, interrupt processor, test program control, discrete executive, display monitor, automatic checkout equipment (ACE) data link executive, DDAS executive, and function executor.

An added capability exists in the operating system program to utilize acceptance test or launch language (ATOLL) executive. This system provides the following capabilities: total operator control of semiautomatic operations, automatic monitoring of parameters, automatic display of parameters, event timing and recording of events on initiation of automated tests, and generation and utilization of ATOLL.

The programs are all written to utilize the redundant capabilities of the hardware system and to recognize the presence of a failure requiring the use of this capability. Each component program operates essentially independently of the other. The interrupt processor maintains the necessary supervisory control of the entire system.

The input/output control system basically controls the operations of the computer peripheral devices; namely, magnetic tape stations, magnetic drums, line printer, card reader, and card punch. The data link executive provides the communication link between the two computers. The display monitor provides all available Saturn ground computer complex data to the display system processor and is responsive to all console operators' requests. The discrete executive controls the discrete system which provides the following:

1) Response to any switch action which, in general, results in the issuance of a discrete output in the vehicle or pad portion of the control and checkout system.

2) Response to signals from the vehicle or the pad portion of the control and checkout equipment which, in general, causes initiation of a discrete output. This lights an indicating lamp on the operator's station at the launch control center. Automatic and inhibited control is also provided.

The Automatic Checkout Equipment data link executive provides communications between the Saturn ground computer complex and the spacecraft Automatic Checkout Equipment system. The DDAS executive allows full access of either or both computers to the DDAS information. The function executor provides the ability to perform many time-critical functions simultaneously for operating programs.

b. Test Programs

Test and monitor programs are the only programs used for automation of checkout, and are the system test engineer's basic operational

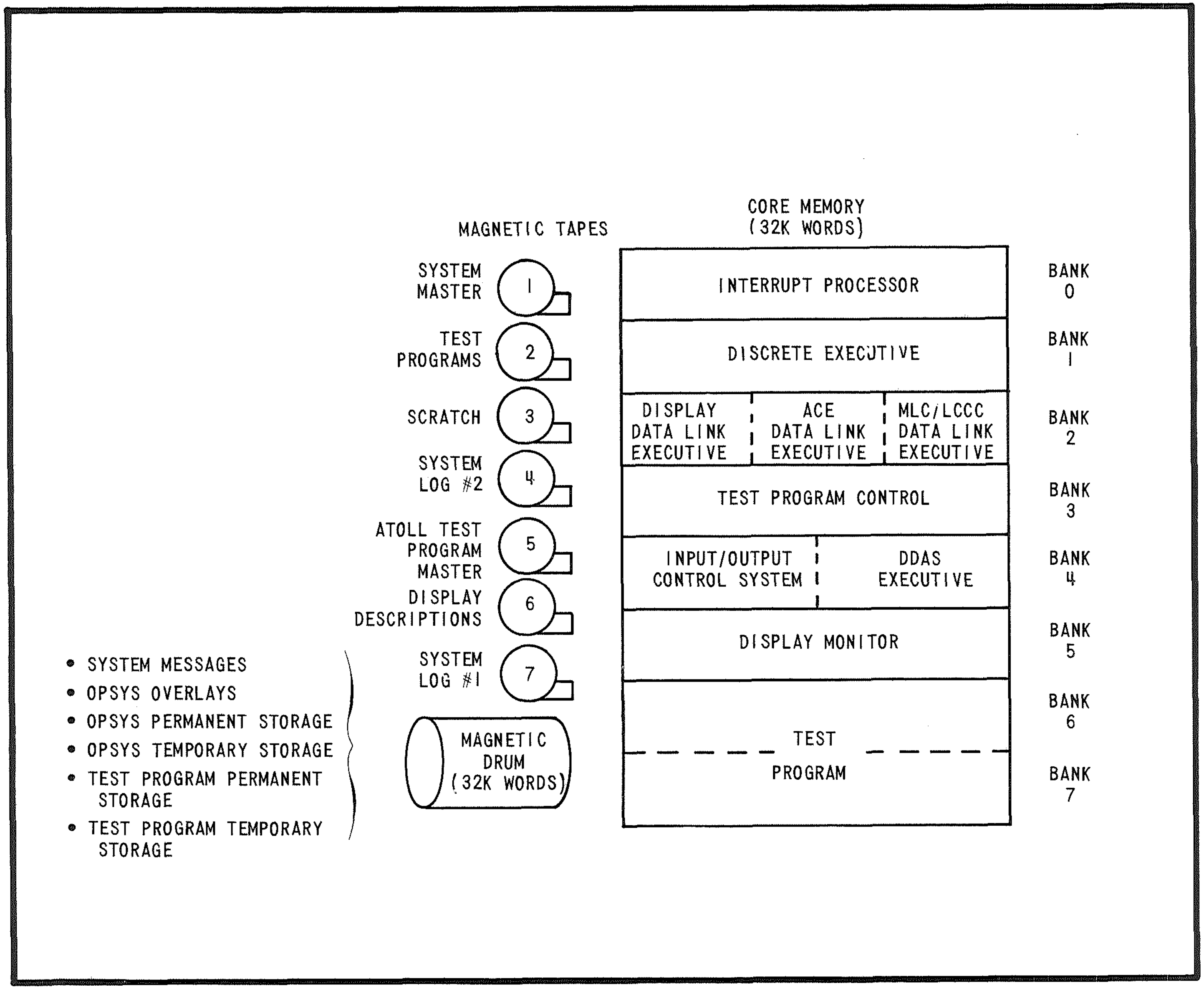

Figure 3-28. Program Storage Allocation, Launch Control Center - Saturn Ground Computer Complex

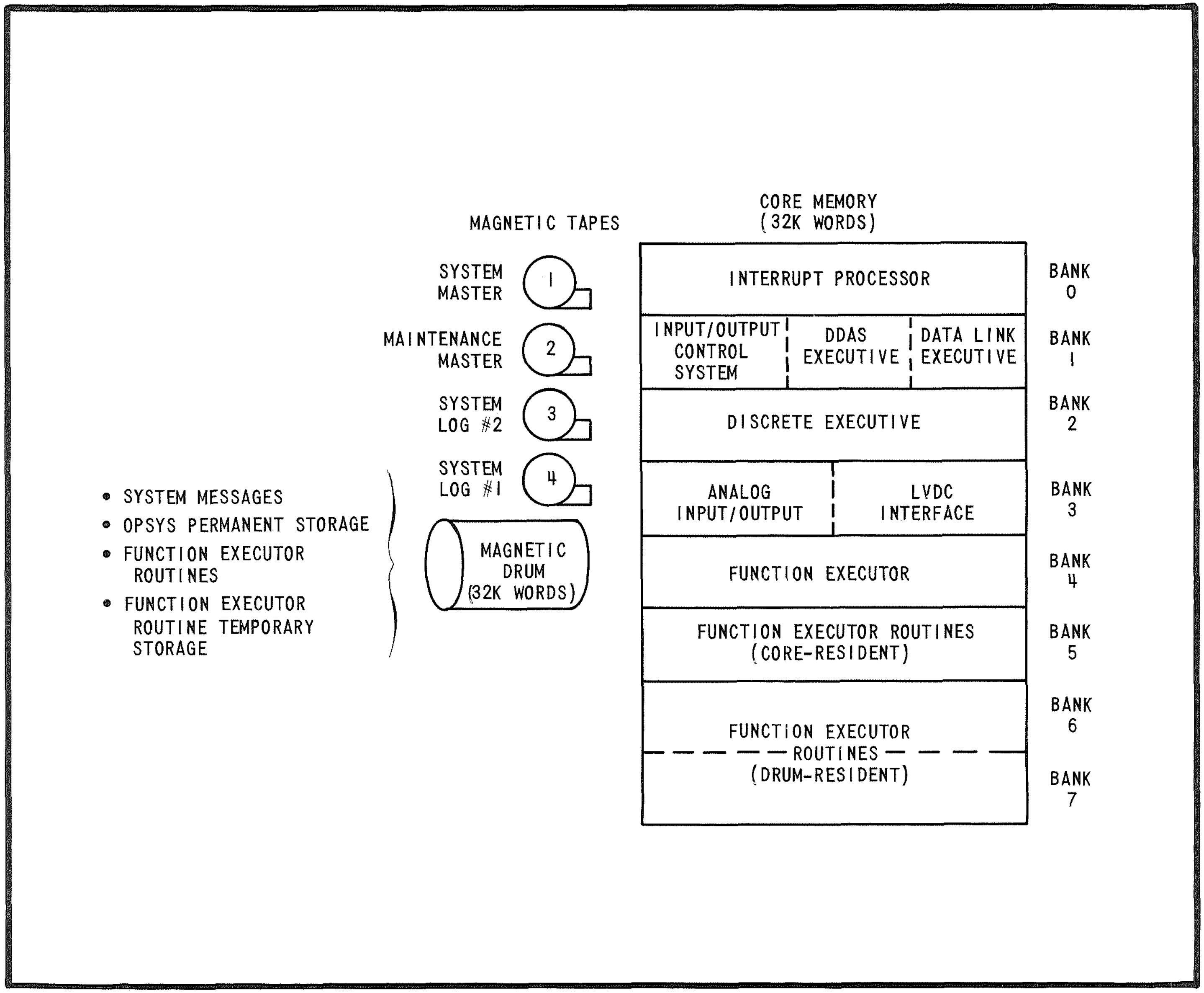

Figure 3-29. Program Storage Allocation, Pad - Saturn Ground Computer Complex

software tool. The generation of test programs can be accomplished in two ways:

1) Use of computer oriented language which utilizes the full capability of the computer logic. This language is also used to document the program printout.

2) Use of acceptance test or launch language, using test engineering oriented language. This language is also used to document the program printout.

Both methods can produce a test program which contains the following capabilities:

1) Sequencing of the required series of events necessary during a checkout of a given system, including required commands.

2) Evaluation of whatever responses result from the commanded sequence of events.

3) Monitoring the system status.

4) Reaction to, or necessary display of, non-nominal operations of preselected alternatives.

5) Sequencing ability to control a number of such programs.

6) Ability to preselect the operation sequence.

7) Ability to change the limits of tested values, both analog and discretes.

8) Ability to intervene.

In addition to the test programs, maintenance and post-test processing programs are used. The maintenance programs fall into two classes, nonoperational and on-line. These consist of computer diagnostic and interface checkout programs for the Saturn ground computer complex and its internal and external interfaces. Post-test processing programs provide the ability to retrieve, log data, convert the raw data into engineering units, and print the information into a format for the test engineer.

D. INSTRUMENTATION SYSTEMS

1. General

The instrumentation portion of the Saturn launch control and checkout system complex (Figure 3-30) is made up of RF and command, telemetry, and measuring systems to perform the following functions:

a. The RF system transmits and receives RF signals to check out and monitor the vehicle command and tracking systems.

b. The telemetry system receives, reformats, and records telemetry data and performs functional and qualitative checks of the various stage telemetry links.

c. The measuring system tests, verifies, and records information from the various sensors and signal conditioning units in the vehicle.

d. The transmission of all telemetry and digital data acquisition system data to the Central Instrumentation Facility for redistribution to other NASA centers, for critical monitoring, and data processing.

The communication link between the vehicle RF and telemetry systems and the ground receiving stations is via both coaxial closed-loop cables and/or open antenna systems, and consists of VHF/UHF RF signals. The digital data acquisition system receiver station input is normally a 600 kilocycle modulated signal fed by coaxial cable from the vehicle. An alternate path for PCM/digital data acquisition system data is provided by RF transmission to the Central Instrumentation Facility and then via closed loop retransmission to the receiving station. The Central Instrumentation Facility loop is used during operational tests when the umbilical plugs are disconnected, and after liftoff during launch countdown. The digital data acquisition system also monitors discrete and analog information from the ground support equipment through a separate ground transmitter. The system interfaces with both Saturn ground complex computers to provide real-time data for display and parameter inputs to automatic test programs.

The data input to the measuring system is from the analog output to the digital data acquisition system and hardwire measurements from the launch vehicle. The system utilizes the remote automatic calibration system for verification of vehicle measuring sensors and signal conditioning units in the vehicle. The calibration system is controlled from the vehicle assembly building on Launch Complex 39, and from the service structure on Launch Complex 34 or 37.

2. Range Safety Command Ground Station

A portion of the RF checkout station is used to verify operation of the range safety command destruct receivers and decoders on the powered stages of the vehicle, and consists of encoders which modulate a RF generator, a receiver for monitoring purposes, decoders indentical to those in the vehicle, and the necessary controls and indicators. The encoder modulates the RF generator with the command functions cutoff, destruct, or system safe for closed-loop transmission to the vehicle stage. A portion of the transmitter output is attenuated and fed back to the ground station receiver, demodulated and decoded, and displayed for self tests of the transmitter system. After reception by the vehicle receiver, the video signal is returned to the ground station where a second decoder displays the command signal for comparison with the previously decoded transmitter signal. This verifies the vehicle stage receivers. The output of the vehicle decoder is available to the ground station through the telemetry system and is used for trouble isolation. The vehicle decoder outputs are also displayed on launch control center panel indicators.

Eastern Test Range commands sent open-loop to the vehicle can be monitored by the ground station and displayed for verification. When the range

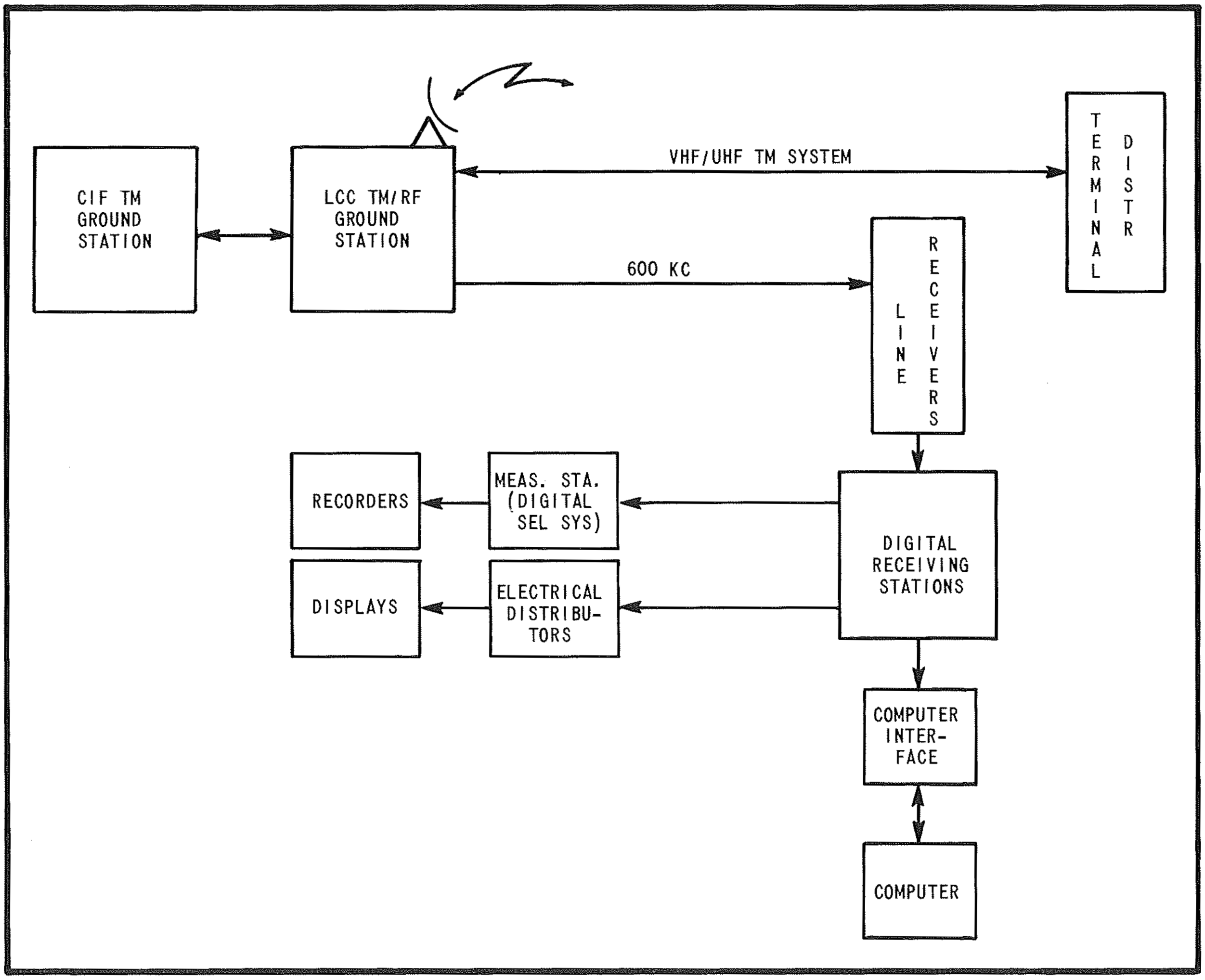

Figure 3-30. Instrumentation System, Launch Control Center (Sheet 1 of 2)

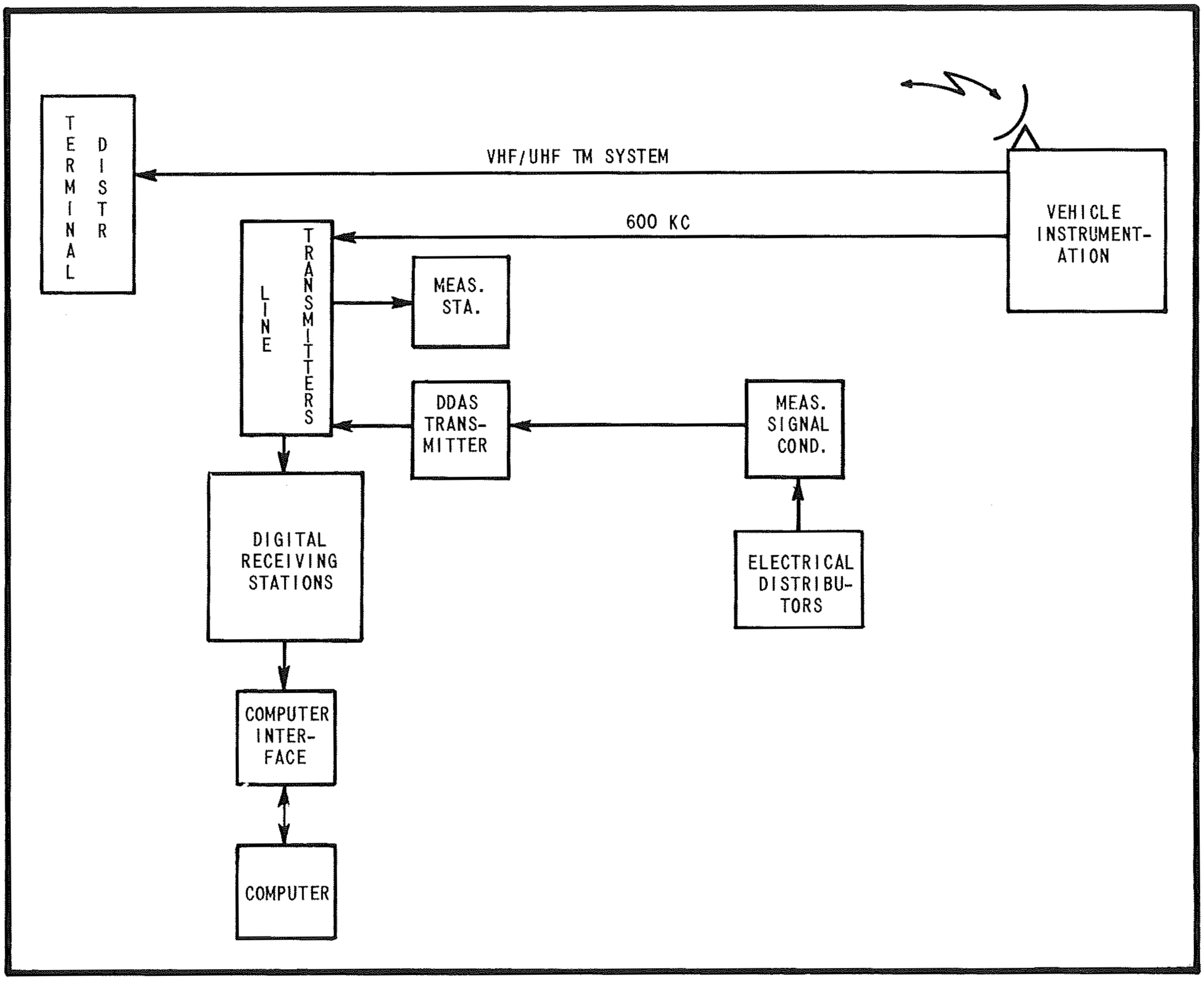

Figure 3-30. Instrumentation System, Launch Control Center (Sheet 2 of 2)

commands are required to be sent closed-loop, the range encoder modulates the ground station RF generator and transmits the signal to the vehicle by the closed-loop system.

3. Digital Data Acquisition System Receiving Station

The digital data acquisition system receiving station (Figure 3-31), located in each launch control center and in the pad area, receives real-time PCM signals which are frequency modulated on a 600 kilocycle carrier from the vehicle telemetry systems and from the ground transmitter in the digital data acquisition system. The receivers demodulate and reformat the signal to a synchronized parallel output. This output is decommutated and stored in a memory core in the computer interface unit for use by the Saturn ground computer complex; and the digital-to-analog converters for display as quick-look data or to the launch control center panel meters and measuring recorders. Digital data acquisition system discrete information is supplied to relay driver circuits and displayed on a launch control center indicator lamp.

A digital signal simulator provides the signal in PCM/digital data acquisition system format for setting up and checking the receiving station. A series of bits, up to four words, is programmed into the format by switches on the front panel and is inserted into the format at an address selected by the controls on the front panel. Two outputs are available: A frequency modulated carrier at the digital data acquisition system frequency (600 kilocycles), and a pulse code modulated wave train.

The quick-look panel allows the operator to select any one desired data channel for display. Data from this channel is presented in both digital and analog form. Ten indicator lamps on the front panel display the selected data in binary form and the channel is converted to analog form and presented on a meter. The quick-look display is normally utilized for setting up and manually testing the receiving station and for malfunction isolation during checkout operations.

Each receiving station is equipped with 100 digital-to-analog converters and two converter calibrators. The converter calibrator performs three basic functions:

a. Provides a means of calibrating the digital-to-analog converters.

b. Permits monitoring of the digital input to any of the converters.

c. Provides the necessary operating voltages to the converters.

The converters utilize the eight most significant bits for conversion and provide the resolution of 0.4 per cent. The converter output is capable of driving strip chart recorders, oscillographs, meters, and other analog display or recording media.

The magnetic tape recording station records the PCM/digital data acquisition system input signal and the data can be retrieved, demultiplexed, converted, and displayed for post-test analysis.

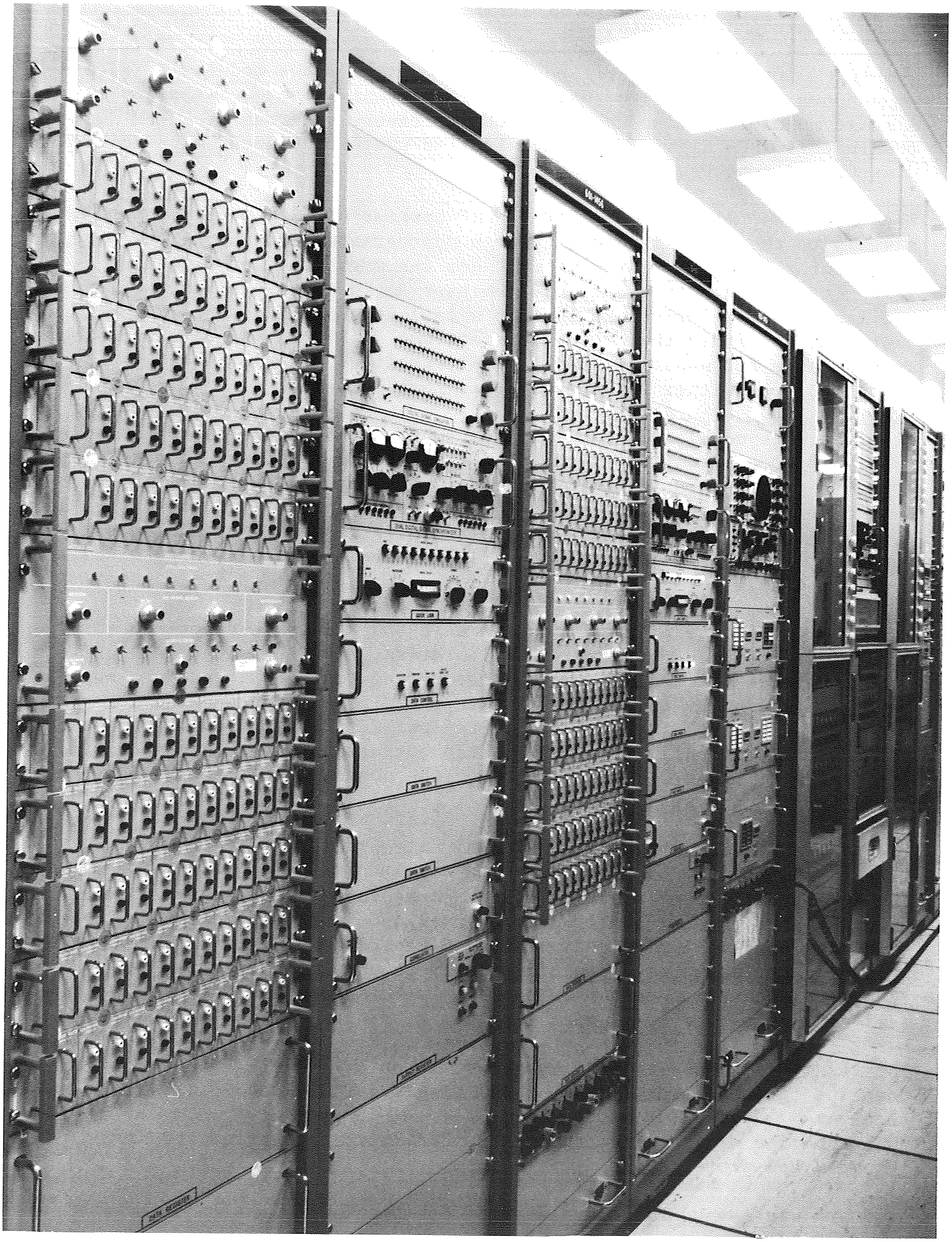

Figure 3-31. Receiving Station, Digital Data Acquisition System

4. Telemetry Ground Station

The telemetry ground support equipment contains stage modules (Figure 3-32) to support the checkout of each individual vehicle stage telemetry system. A stage module contains a bank of VHF receivers, a group of FM/FM discriminators, PCM/digital data acquisition system equipment, and related display and test equipment.

The receivers, after removal of the RF carrier signal, supply the video signals to the discriminators through appropriate patching at the patch distributor. The RF test equipment has the capability of measuring transmitter center frequency, transmitter deviation, receiver sensitivity and linearity, relative transmitter signal strength and subcarrier distribution within the frequency spectrum. A RF test signal generator is available for substitution of the transmitter signal and can be modulated from either an internal or external source.

The frequency modulated discriminator equipment demodulates the selected, frequency modulated video signal and consists of 19 discriminators, data measuring and monitoring test equipment, and patching and selector panels. A test oscillator provides test signals for calibration of the discriminators. The airborne subcarrier oscillators' preemphasis schedule can be verified by either calibrated measuring equipment, meters, or a visual spectrum display.

The decommutation equipment consists of a 600 kilocycle discriminator, digital-to-analog converters and calibraters, a quick-look panel, pulse code modulated synchronization and formatting equipment, and data switching. The equipment is very similar to the digital data acquisition system receiving station but is limited to ten outputs from the converter, used primarily for trouble isolation. These outputs and frequency modulated discriminator outputs are available to the common module for display on oscillographs and strip charts.

The telemetry ground support equipment common module (Figure 3-33) is used by all vehicle stages, and telemetry information is recorded here on 14-channel magnetic tape stations. The module contains frequency modulated discriminators, pulse amplitude modulated decommutation equipment, single-side band demultiplexing equipment, and control and display equipment, including strip charts and oscillographs to support checkout of all stages. Individual measurements can be patched to the recorders and verified in real-time or played back using the tape recorders for post-test evaluation.

The telemetry ground support equipment interface module (Figure 3-34) contains telemetry receivers for all stages. The video signals from these receivers are fed to multiplex equipment and transmitted over the wide-band cables to the Central Instrumentation Facility where telemetry data is recorded and processed as necessary.

5. Vehicle Measuring Ground Support Equipment

The measuring station patch panel (Figure 3-35) allows any stage measurement, either hardwire or digital data acquisition system, to be patched to

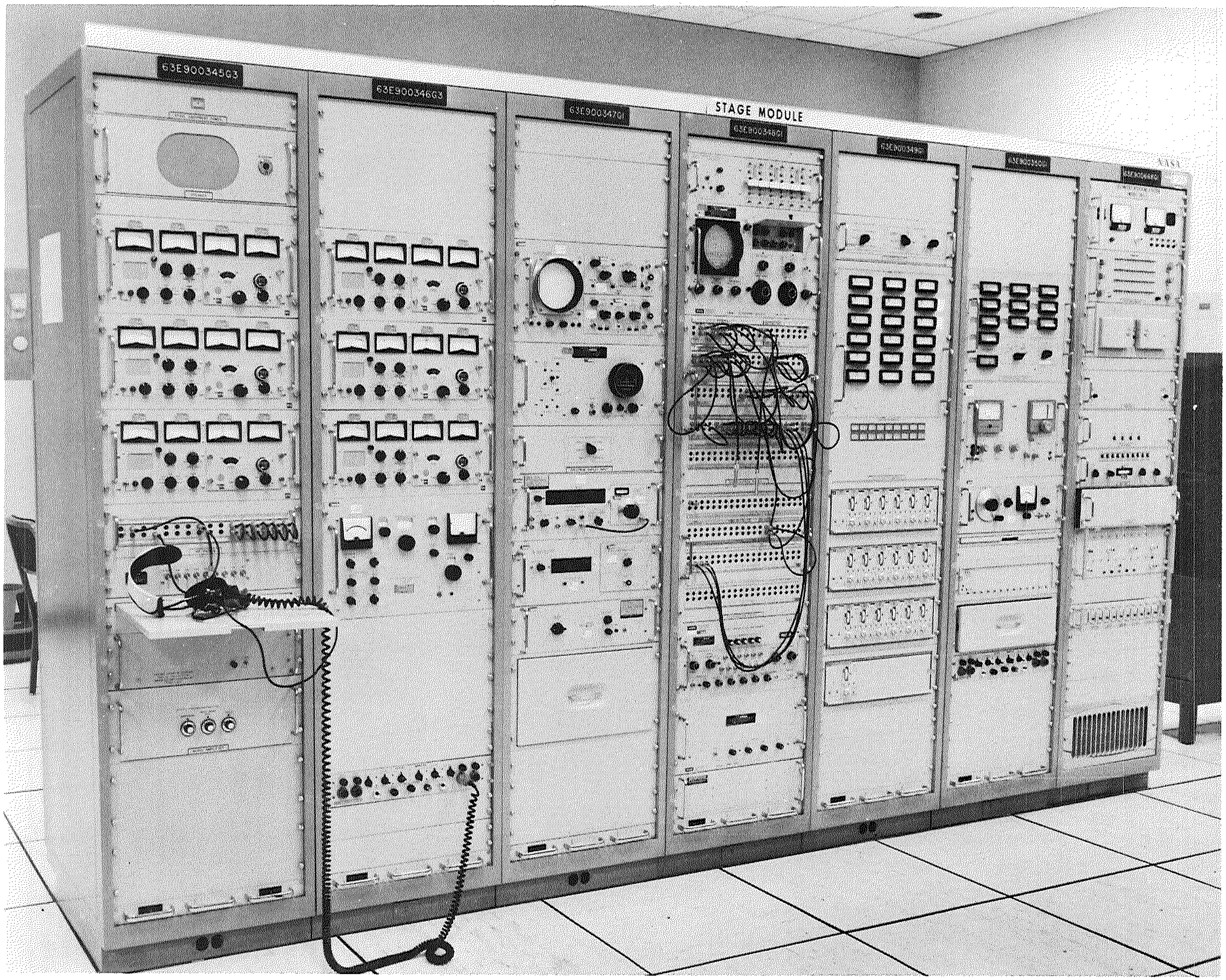

Figure 3-32. Telemetry Checkout Stage Module

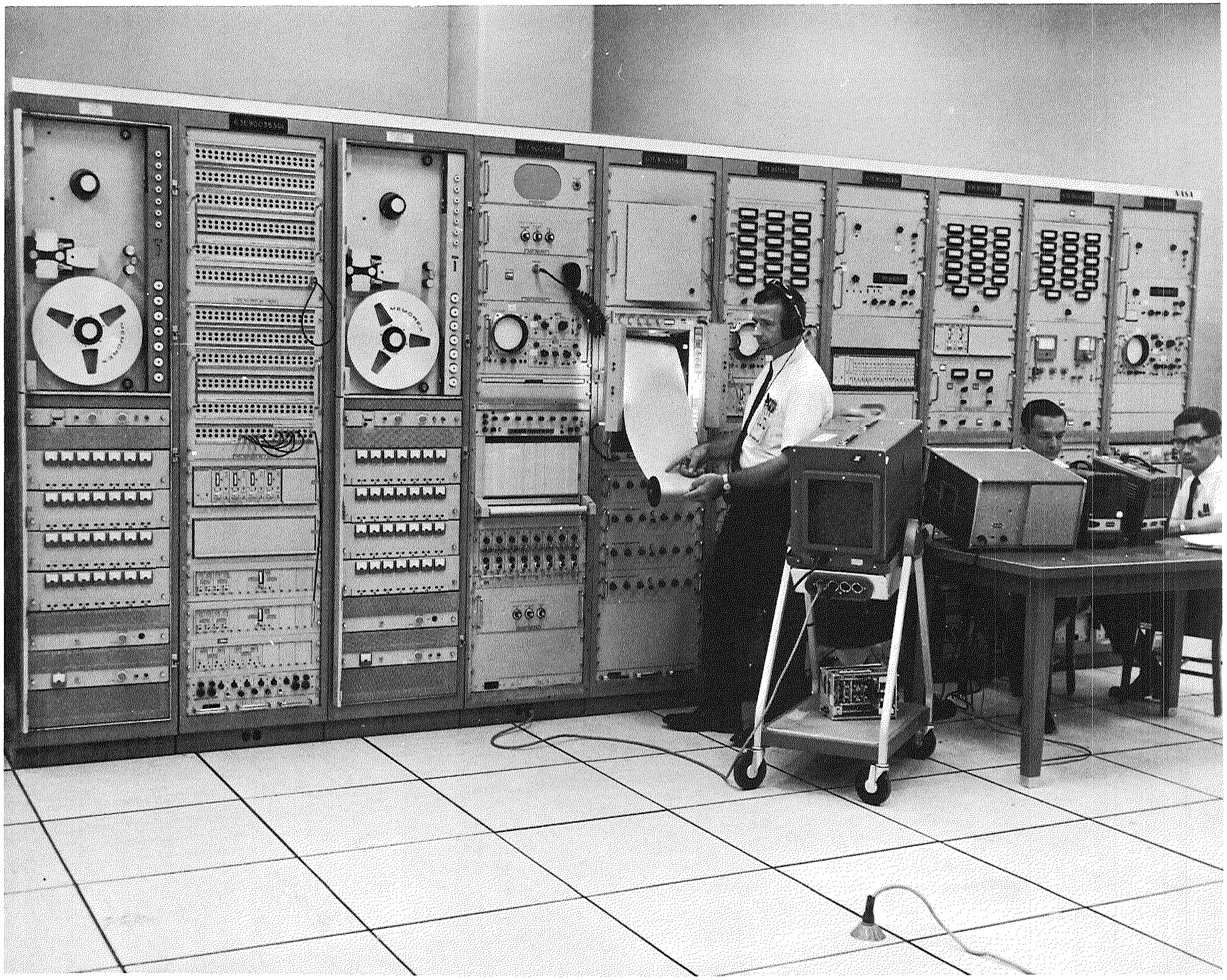

Figure 3-33. Telemetry Checkout Common Module

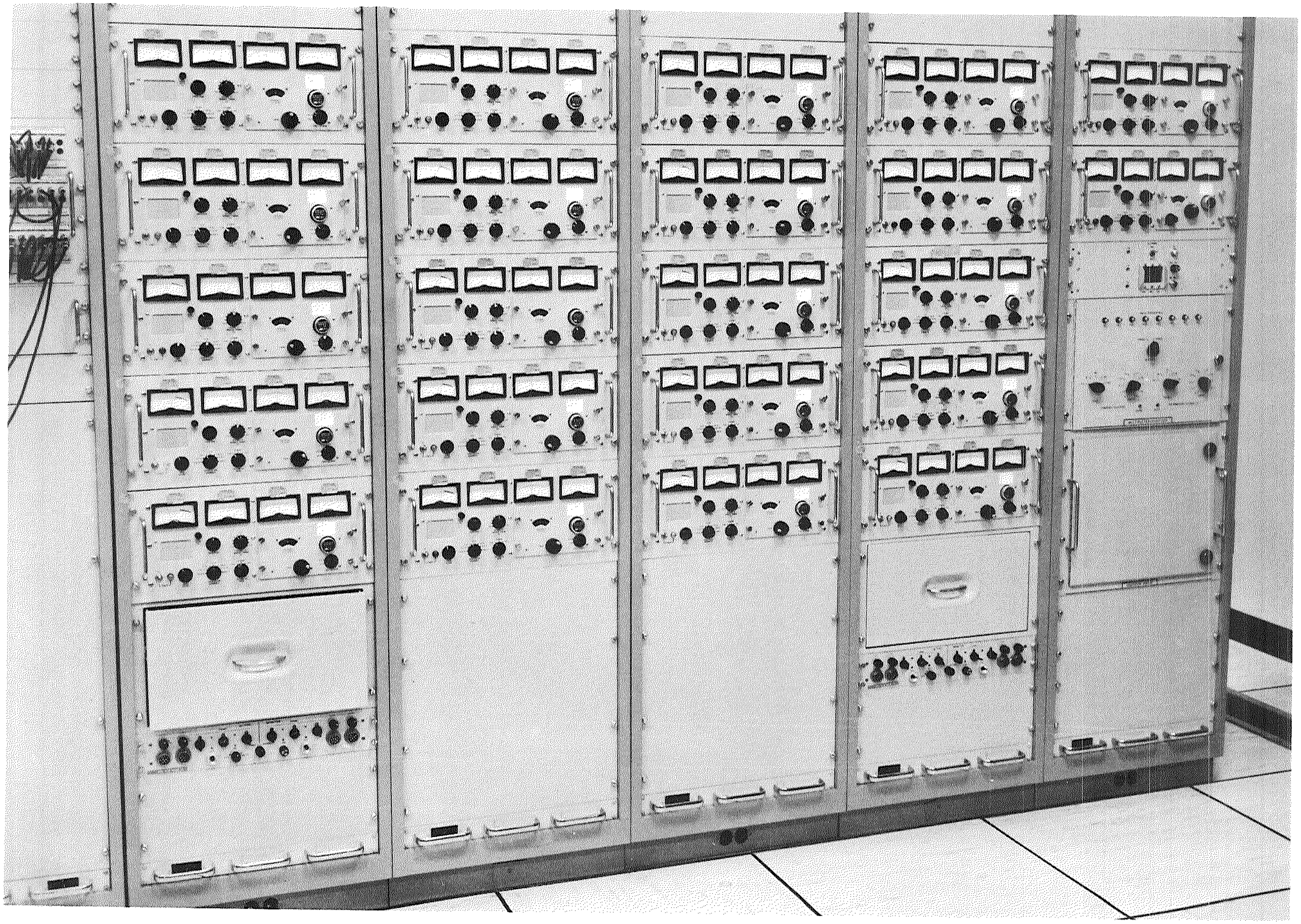

Figure 3-34. Telemetry Interface Module

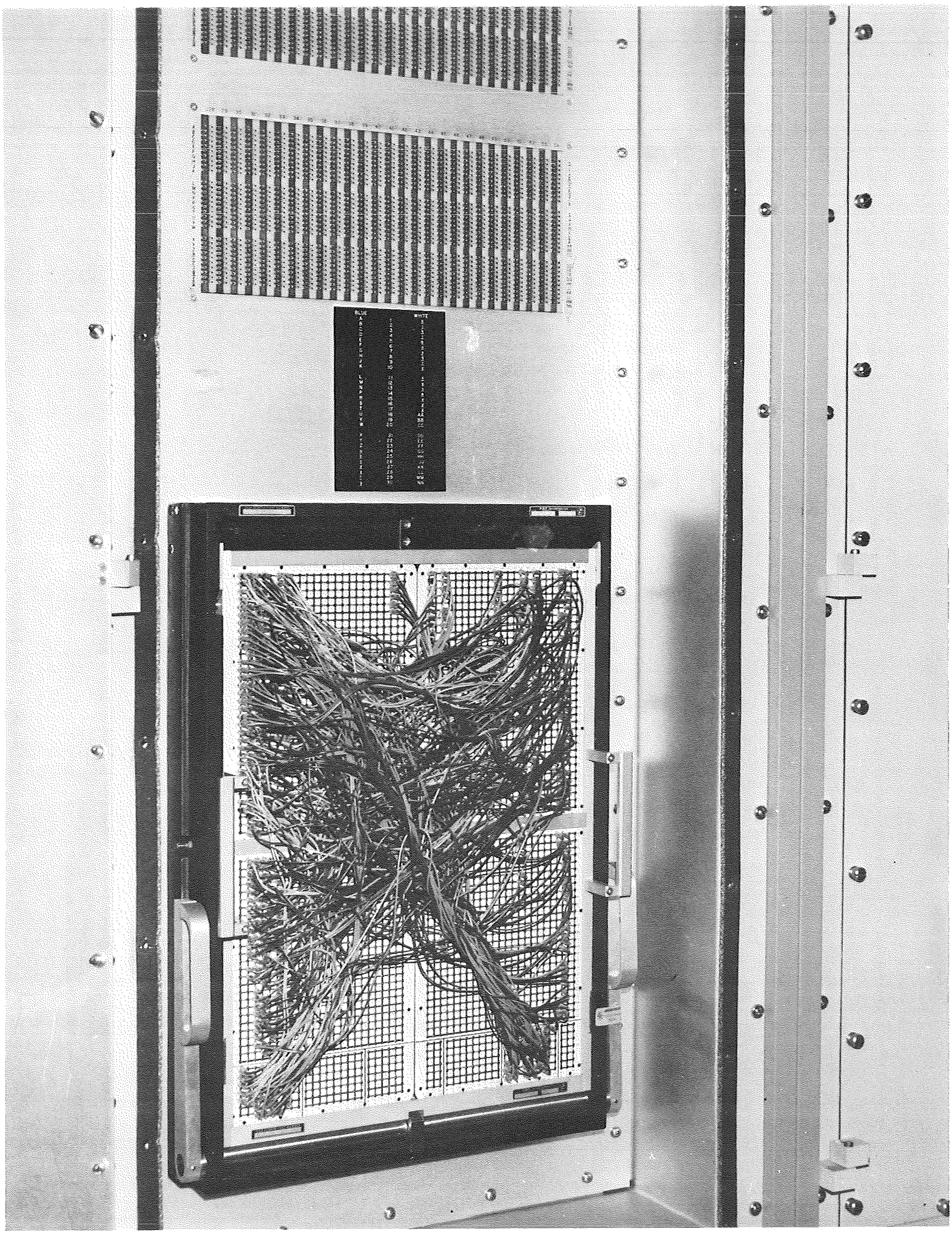

Figure 3-35. Measuring Station Patch Panel

any strip chart recorder in the firing room. The upper panels are input and output test points which allow troubleshooting to be performed without disconnecting the patch cords.

The firing room measuring station strip chart recorders (Figure 3-36) record measurements primarily for monitoring red-line values of mandatory measurements, although some highly desirable measurements are also recorded. At the calibration test position (Figure 3-37), signal conditioners and transducers are verified to be within specified tolerances of the measuring calibration curves prior to use in support of other tests. The remote automatic calibration system is used to supply the calibration signal, and the digital data acquisition system is used to display the analog and digital readout for verification.

The measuring module test set (Figure 3-38) is used to test signal conditioners and transducers, after removal from the stage, for trouble isolation or prior to installation of spare units. The test set includes power supplies, a digital voltmeter, a signal generator, an oscilloscope, a digital printer, and the module test panel. The unit to be tested is connected to the test panel through adapter cables and vehicle conditions relating to input/output impedance. Input signals are simulated by the test panel. Verification of proper operation is made using the digital printer.

The measuring analog recorder (Figure 3-39) is used to record certain measurements pertaining to a particular test operation. These measurements are selected prior to the test by patching or digital-address-select panel. The equipment consists of an oscillograph and strip chart recorders, digital-to-analog converters and calibraters, and patching and select panels. The records are utilized for post-test evaluation or real-time trouble isolation.

E. CENTRAL INSTRUMENTATION FACILITY

The Central Instrumentation Facility is located in the Industrial area of the space center and is the focal point for telemetry support of major prelaunch tests and launch. The telemetry GO/NO-GO parameter evaluation for the launch vehicle is made at this facility, and all out-of-tolerance parameters are reported to personnel in the launch control center. The telemetry station (Figure 3-40),located in the Central Instrumentation Facility, is composed of several modules which can be operated either together or independently. The telemetry system provides the following services:

1. Acquisition and recording of telemetry data.

2. Analog recording of processed telemetry data.

3. Real-time digitizing and selection of telemetry data for reduction on general purpose computers.

4. Digitizing, reformatting and selection of telemetry data for real-time digital transmission to other NASA centers or other data users.

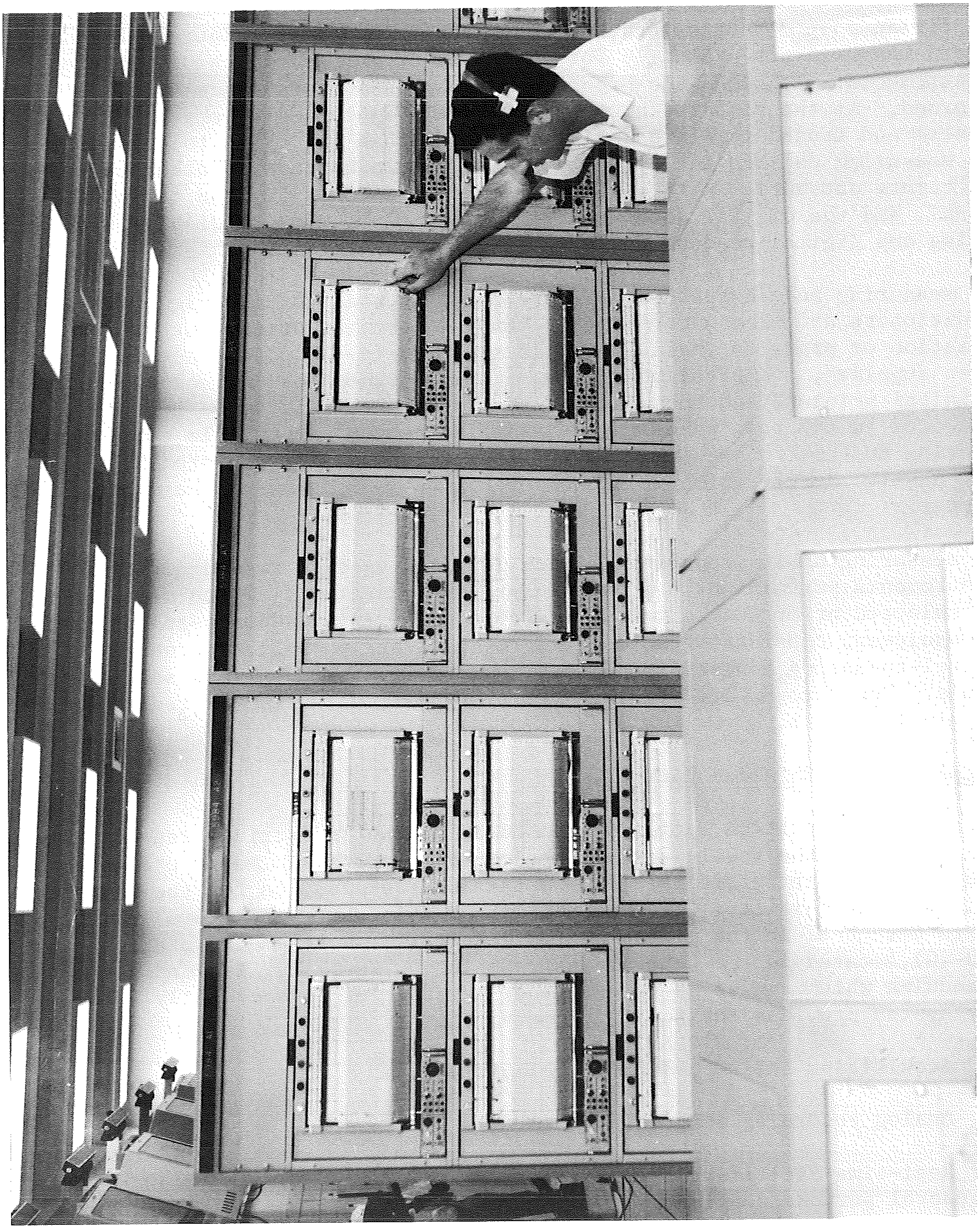

Figure 3-36. Telemetry Strip Chart Recorder

Figure 3-37. Measuring Calibration Test Position

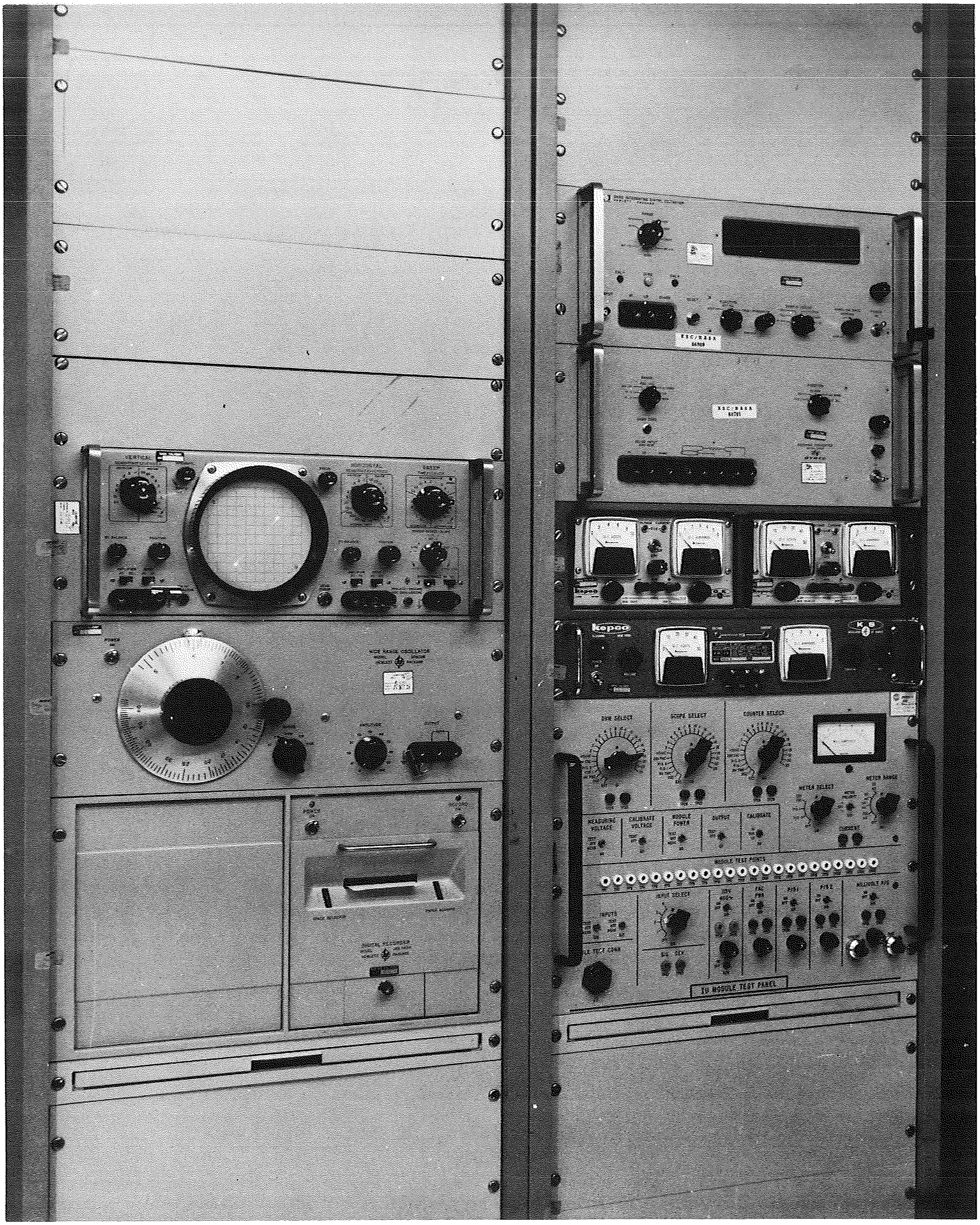

Figure 3-38. Measuring Module Test Set

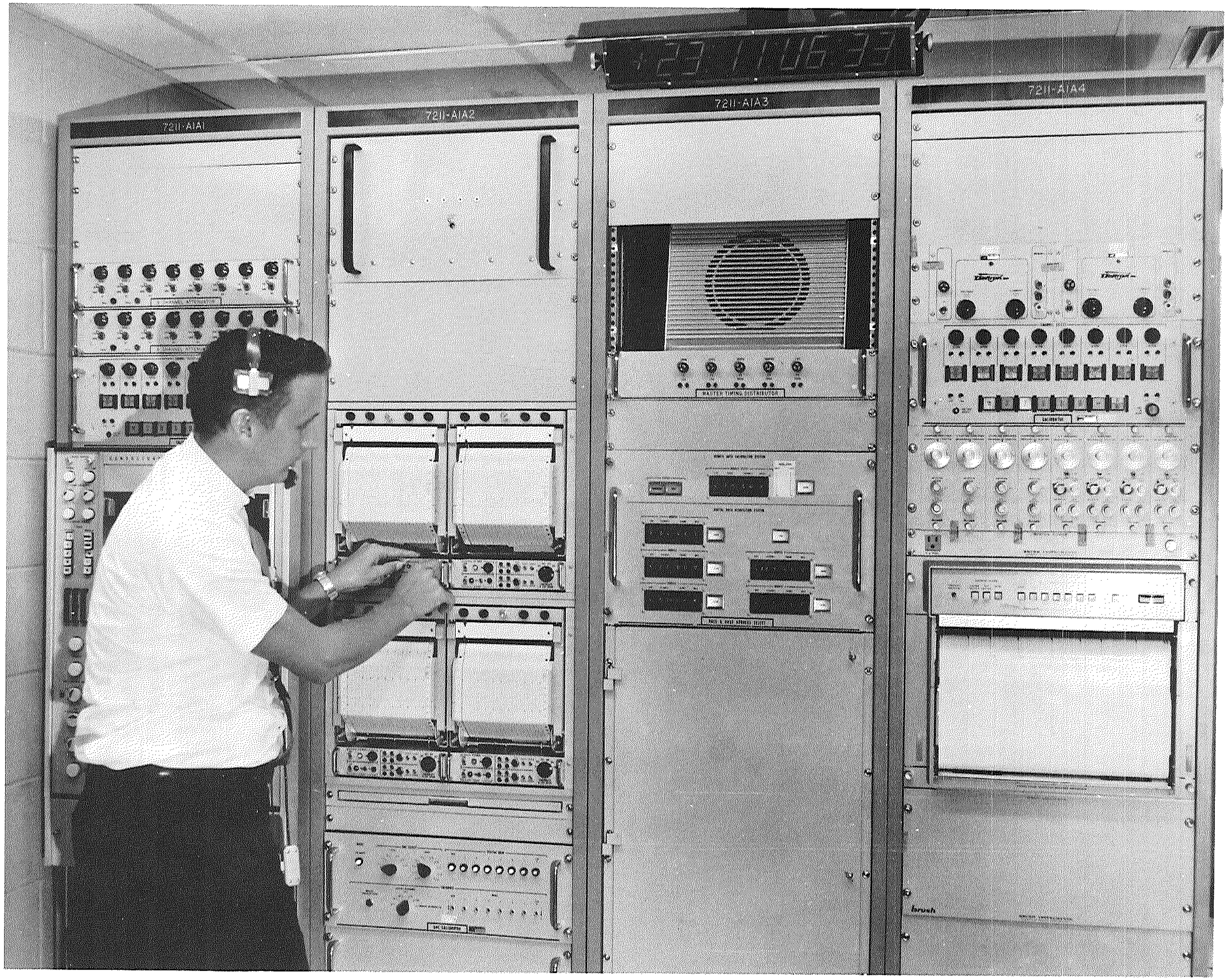

Figure 3-39. Measuring Analog Recorder

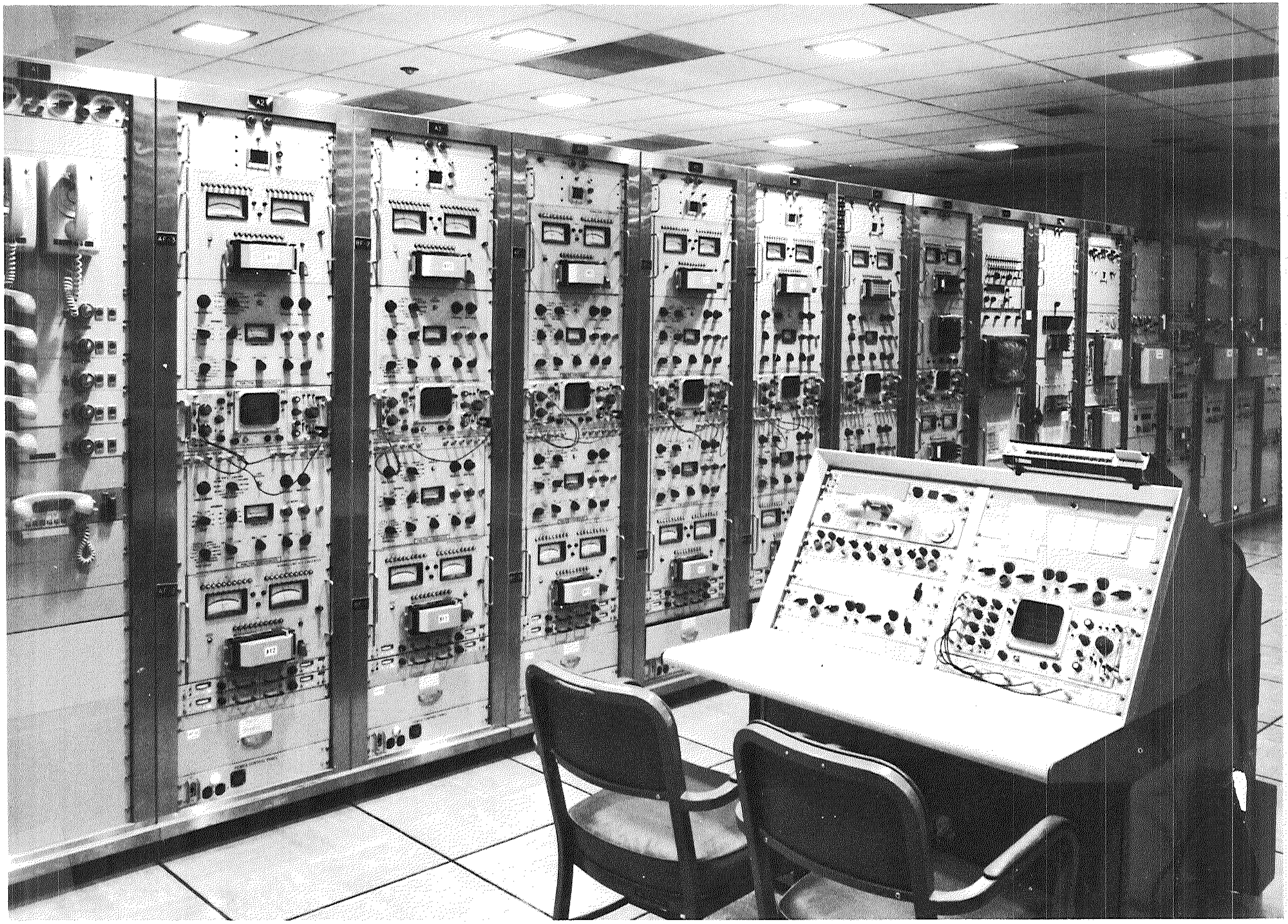

Figure 3-40. Telemetry Station, Central Instrumentation Facility

5. Generation of computer compatible digital tapes of telemetry data for computer reduction.

6. Real-time telemetry readouts for operational personnel.

The data core (shown in flow diagram, Figure 3-41) receives, converts, collates, and stores telemetry data from multiple sources and provides random access to its continually updating memory core for various Kennedy Space Center and off-site, real-time data systems. The data core is capable of receiving PCM/PDM/PAM and analog signals which are processed and stored in a digital format ideally suited for direct utilization by high speed digital computers.

The equipment at the real-time monitor consoles in the data display room (Figure 3-42) of the Central Instrumentation Facility includes two cathode-ray tube displays, three eight-channel strip chart recorders and three, 20-channel event recorders. From the cathode-ray tube display console, page format and graphic display information is called from the data core through the digital computer. The page format is capable of displaying 16 measurements per page. A digital select system allows any vehicle analog measurements to be called from the data core and recorded on the strip charts, or discrete information called from the data core and displayed on the event recorder.

The launch information exchange module (Figure 3-43) is the information link between Kennedy Space Center and Marshall Space Flight Center, over which direct engineering support is provided in areas of propulsion, navigation and electrical networks. The Launch Information Exchange Facility supports the major test during prelaunch checkout in addition to the launch countdown. Telemetry data from the data core is transmitted to Marshall Space Flight Center by wideband transmission circuits at a rate of 40.8 kilobits per second. Real-time parameter selection is controlled from Marshall Space Flight Center by serial PCM messages transmitted at a 2.4 kilobit per second rate. In addition, the following types of information exchange capabilities are provided through the Launch Information Exchange Facility.

1. Magnetic tape and punch card digital data.
2. Facsimile.
3. Countdown timing and liftoff signal.
4. Closed-circuit television images.
5. Classified teletype information.

F. SYSTEM INTEGRATION

The typical Saturn control and monitor circuit (Figure 3-44) illustrates the integration of the many separate elements of checkout equipment into one functional system. The double-pole, three-position switch in the launch control center, from which a command originates, functions as follows:

1. On Position

A discrete input (DI 402) is sensed at the launch control center computer discrete input data channel, and a message is transmitted to the pad computer to issue a discrete out (DO 402) through the discrete output relay drivers to electrical networks relay K12.

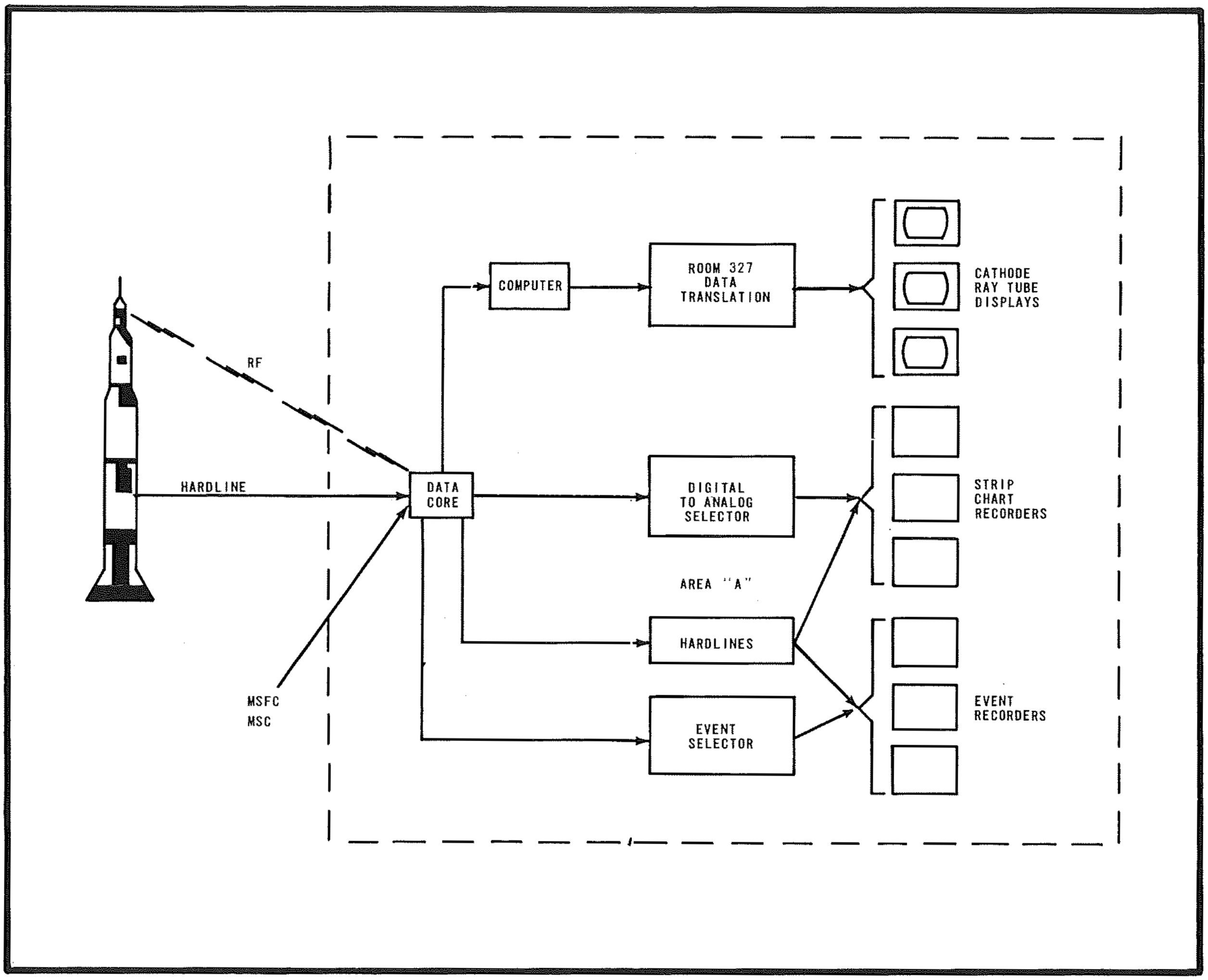

Figure 3-41. Data Flow Diagram, Central Instrumentation Facility

Figure 3-42. Data Display Room, Central Instrumentation Facility

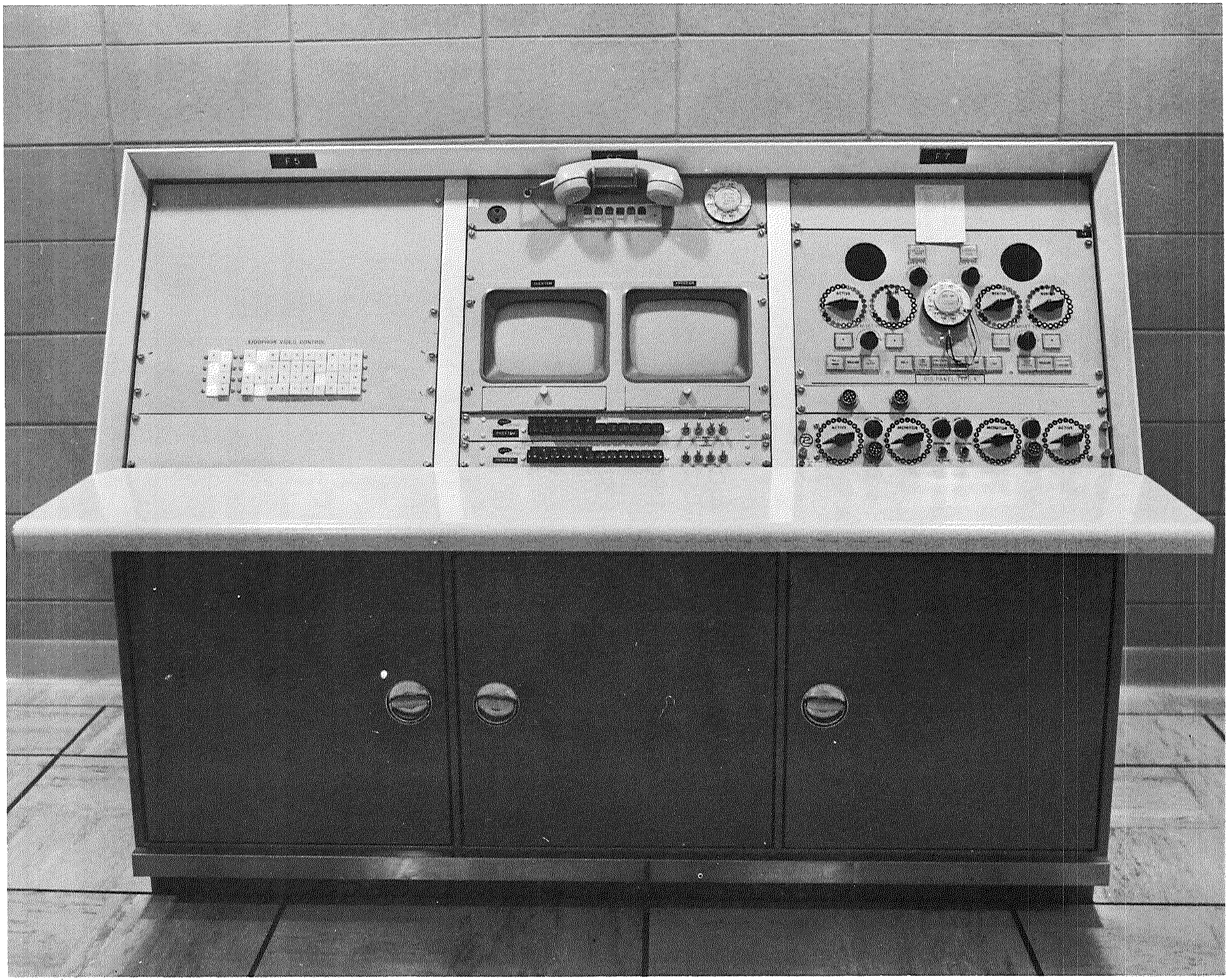

Figure 3-43. Launch Information Exchange Module

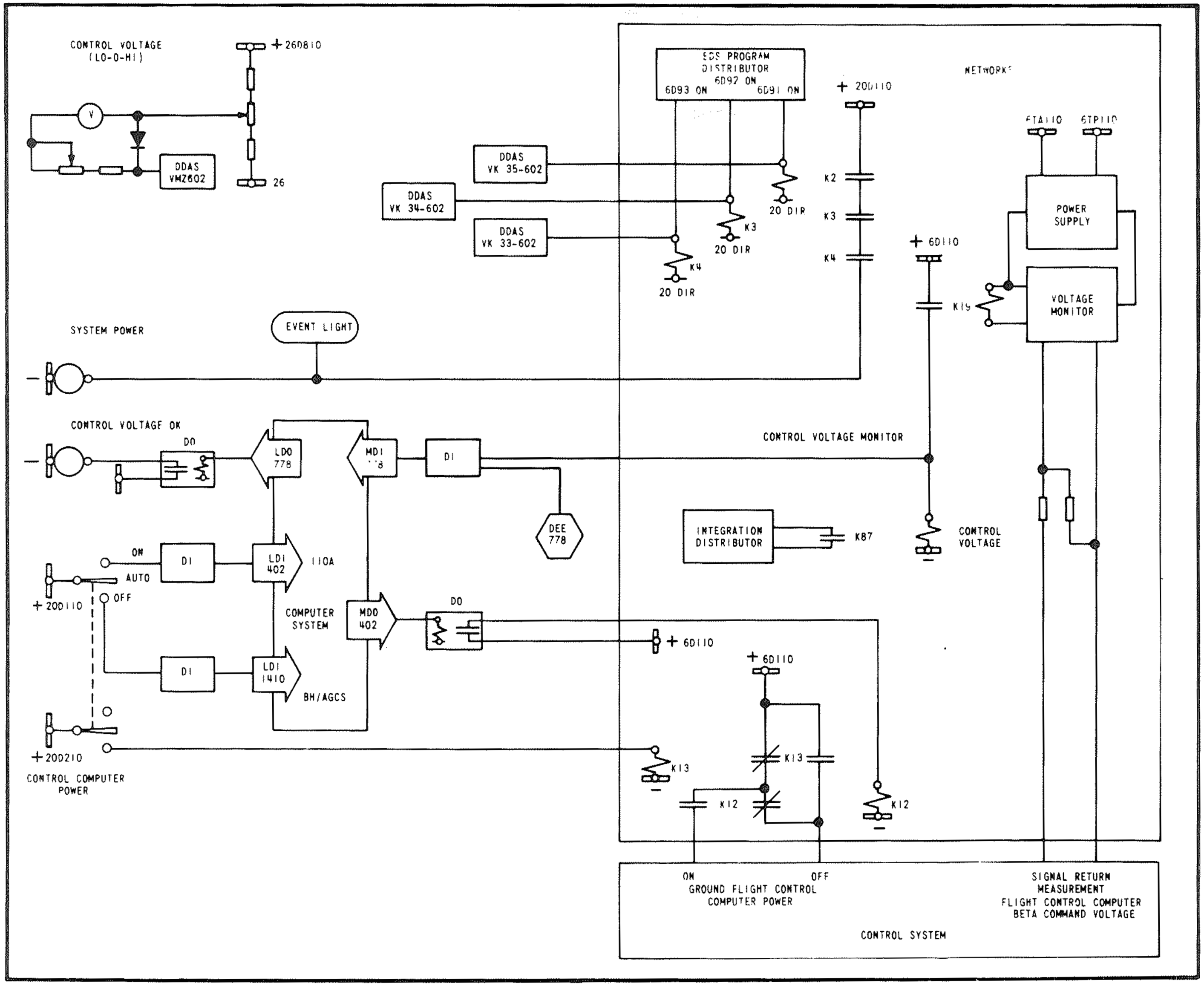

Figure 3-44. Typical Saturn Control and Monitor Circuit, Integration Schematic Diagram

2. Off Position

The discrete input at the launch control center computer (DI 1410), through computer logic within the executive program, transmits a message to turn off discrete output (DO 402) and inhibit further issuance of this discrete. The off position through the other pole of the switch provides the hardwire emergency type signal to relay K13 for turn-off of the vehicle component.

3. Auto Position

In the auto position, the inhibit is removed and discrete output (DO 402) can be issued under computer test program control for automated checkout of the circuitry.

The control logic (relays K12 and K13) is such that a single failure in either branch of the critical circuit (in this case the off-side of the switch) will still result in the desired command at the ground support equipment vehicle interface.

The feedback from the vehicle component is transmitted to the ground by two separate means:

1. Via the digital data acquisition system (VMZ 603) where, after conditioning by the ground receiving station, will be displayed in analog form on the control panel meter for visual surveillance by the test engineer.

2. Via hardwires to the special monitor circuits in the pad area where, if the voltage is at the proper level, relay K19 will be energized.

The power supply provides the calibration voltage necessary for comparison within the monitor circuits. Relay K19 provides a discrete input to the digital events evaluator for recording or real-time analysis, and into the Saturn ground complex computer system for display on the control panel indicator lamps. Relay K19 also energizes relay K87 to route the signal through the integration patch distributor to interface with other stage electrical ground support equipment for interlock purposes. Relay K87 is a buffer necessary to isolate the dc buses when signals are interlaced between various vehicle stages. Contacts of relay K87 are fed by the stage bus utilizing that particular signal.

Associated signals are monitored by the ground digital data acquisition system (VK 33, 34, and 35) and by hardwires for display on the control panel and events display panel. All vehicle and ground digital data acquisition system information is available to the Saturn launch computer for parameter inputs to automatic test programs, or to the Central Instrumentation Facility and various telemetry recording stations for recording or malfunction analysis.

SECTION IV
OPERATIONAL EXPERIENCE

INTRODUCTION

The space vehicle umbilical eject overall test sequence as described in Section II did not consider the possibility of problems or holds during the test. Experience at the launch site has shown that problems can exist and that a hold may be anticipated until suspected problems are isolated. In order to explain how the Saturn/Apollo control and checkout system is used to isolate suspected problems, typical hold conditions that could occur during the overall test will be described. The six conditions will be as follows:

1. Procedure for applying power to the Saturn ground computer complex remote (mobile launcher) computer, utilizing the remote control system located in the launch control center.

2. Suspected issuance of an erroneous discrete output during operational steps.

3. Indication of multiple output from switch selector command; suspected program error.

4. Suspected emergency detection system malfunction.

5. Cutoff after start of terminal countdown.

6. CALIP (pressure switch) system.

A. POWER-UP PROCEDURES

As the first condition, procedures for applying power to the remote computer of the Saturn ground computer complex, utilizing the remote control panel, located in the launch control center, will be described to explain the steps taken in anticipation of a problem that would normally require manned access to the remote computer.

The capability to control the remote computer is provided through the use of the remote system consisting of an electrically controlled mechanical device and two control consoles, for both local or remote control. The system can mechanically actuate all the necessary pushbuttons and switches on the magnetic tape stations (Figure 4-1), data link system, main computer power source, and the remote computer maintenance panel (Figure 4-2). Operational TV provides visual monitoring. The design features are as follows: low cost, portability, easily attached and detached, no electrical interface with computer logic, simple one-time mechanical adjustment, simple electrical control circuits, and identical controls.

The use of the remote control system during this test is to validate its operation. The procedure is as follows:

Figure 4-1. Overall View of Magnetic Tape Stations

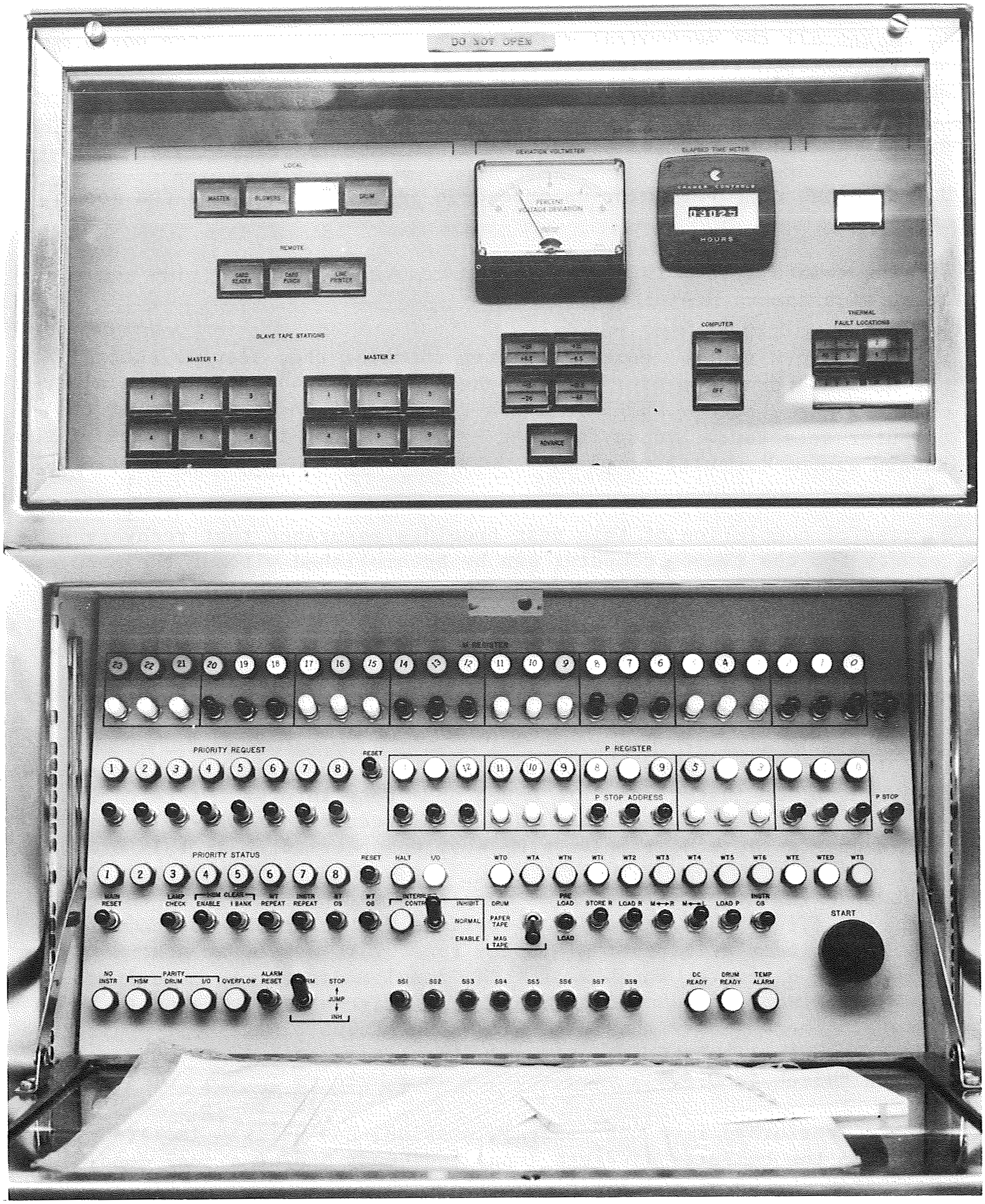

Figure 4-2. Pad Computer Maintenance Panel

1. After all the mechanical maintenance procedures have been performed, and the necessary magnetic tape stations loaded, the mechanical (maintenance panel) actuators (Figure 4-3) are installed.

2. All necessary cabling is connected and power is provided.

3. A normal computer power-up procedure is performed using the local console.

4. The remote system is placed in the remote control position and the television camera positioned.

5. The launch control center computer operator then assumes control at the Saturn ground computer remote panel (Figure 4-4), and starts a normal power-up sequence which includes the loading and execution of the computer acceptance tests, followed by loading and initialization of the Saturn ground computer complex.

Successful completion of this test provides assurance that recovery procedures for the remote computer can be accomplished without the need of sending personnel into a hazardous area.

B. SUSPECTED ISSUANCE OF ERRONEOUS DISCRETE OUTPUT

In the second condition, an issuance of erroneous discrete output during operational steps is suspected.

The count is T-5 hours 5 minutes and instrument unit power-up procedures have started. One of the instrument unit panel operators informs the test conductor that one of the indicating lamps has illuminated erroneously. The test conductor requests the electrical system test engineer to check this problem.

The engineer determines from the coded decals on the panel face of the computer consoles (Figure 4-5) that the circuit is controlled by the computer system. The engineer utilizes the display console to sense the status of the vehicle response discrete, which causes the panel indicator to illuminate, and to sense the vehicle command discrete. All discretes are found to be in the ON state. The engineer then determines the status of the switch discrete at the launch control center computer and finds it is also in the ON state, although the switch is OFF.

This process, performed from one central location, has quickly isolated the malfunction to the computer discrete input equipment and/or signal conditioning. Voltmeter checks at the signal conditioning output test points verify the proper operation of this equipment.

The engineer informs the test conductor that the discrete output system will be inhibited and sets the launcher discrete output inhibit switch, thereby causing the Saturn ground computer complex to drop down to an IDLE mode. A

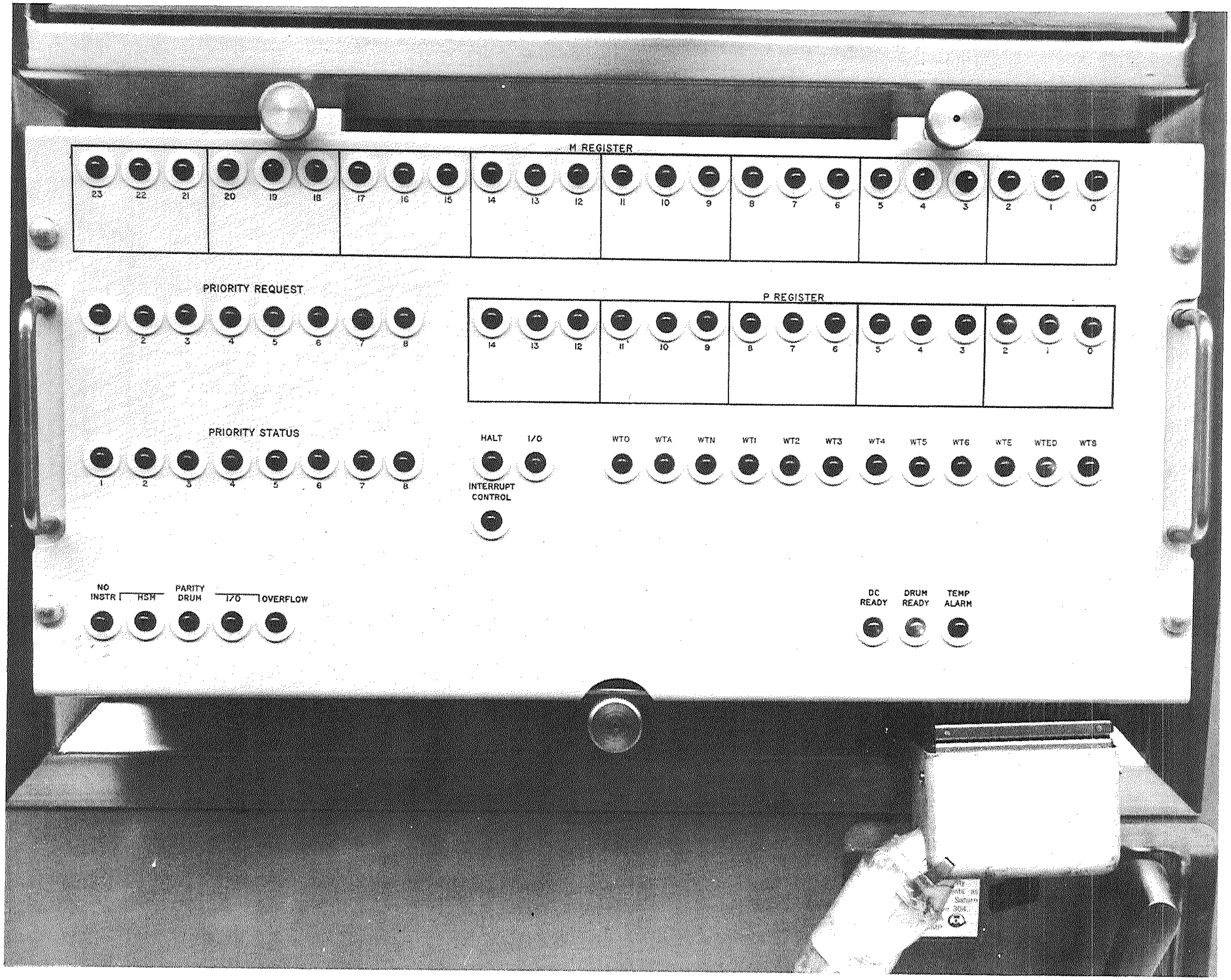

Figure 4-3. Maintenance Panel Actuator

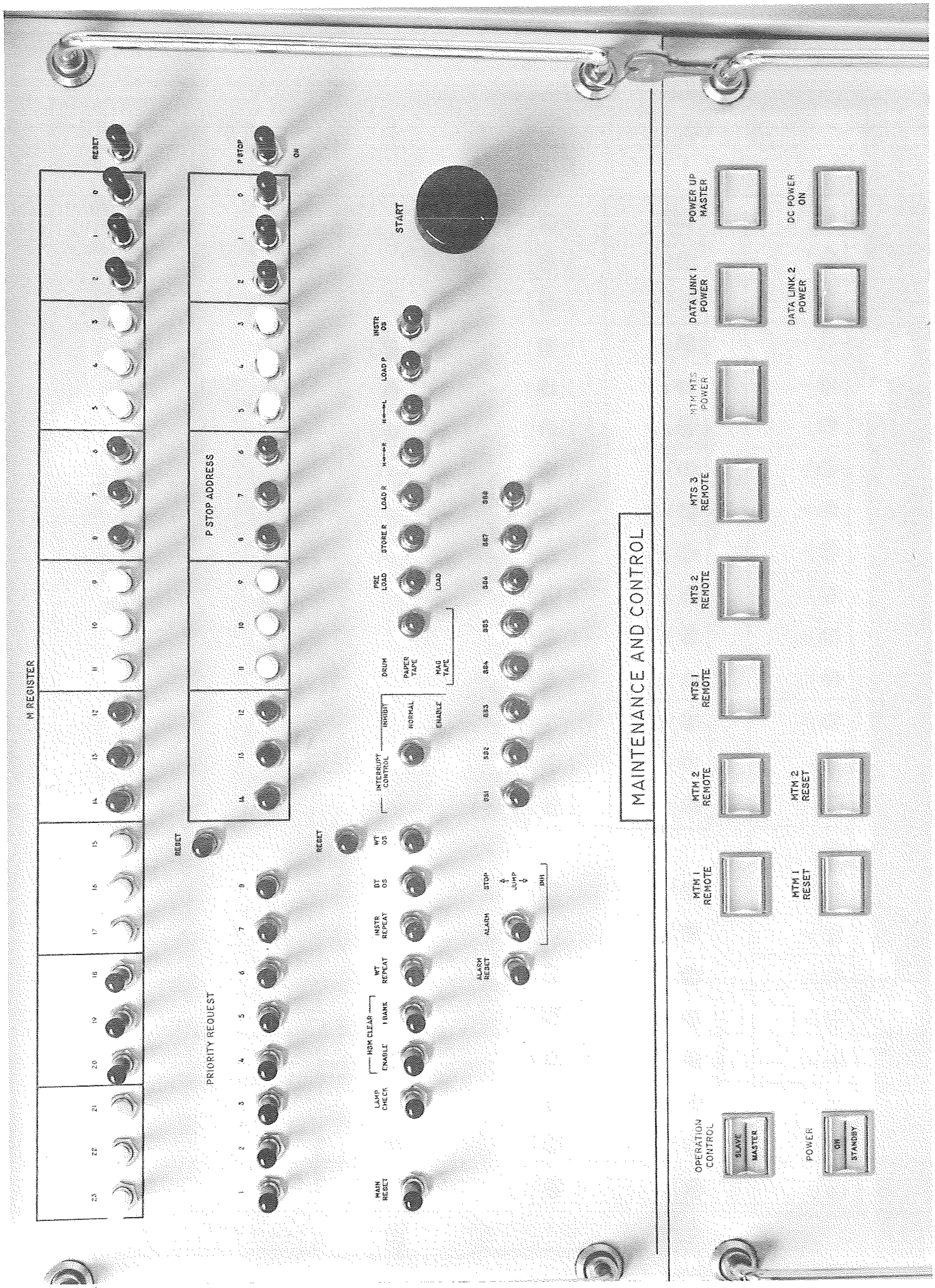

Figure 4-4. Saturn Ground Computer Remote Control Panel

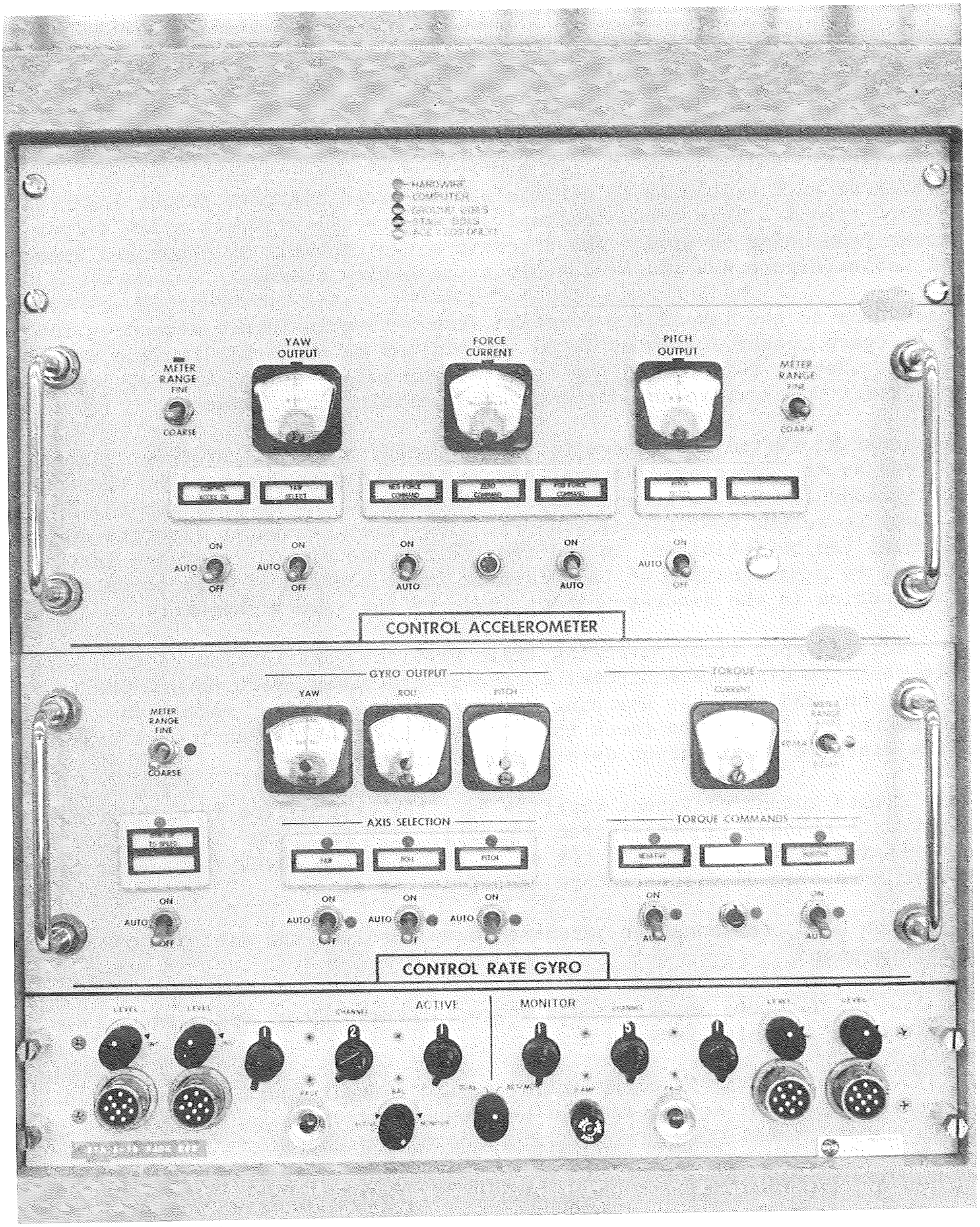

Figure 4-5. Flight Control Computer Consoles

message is displayed on each display console indicating the computer system is in the IDLE mode. This mode prevents any changes in discrete output signals to the vehicle. At this point, the test conductor requests a hold and asks the computer operator for a time estimate of the hold. A half-hour estimate is given.

At this point the inhibit switches will be discussed. There are two discrete output inhibit switches in the LCC control room; one for each computer. The function of each switch is to set the parity error discrete output logic with a ground signal. This then, logically, prevents all discrete relay driver outputs from being changed. The discrete output inhibit switches and associated table (Figure 4-6 and 4-7) reflect the entire scheme.

In addition to the manual intervention, the automatic launch sequencer inhibits the discrete output system at T-186 seconds and removes this inhibit at T+3 seconds. During this period the computer normally does not have to issue any discretes. However, in an emergency, the inhibit can be blocked.

The operating system downgrades to the IDLE mode when the interrupt signal is received by the computer. Removal of the inhibit signal sensed by the computer upgrades the Saturn ground computer complex to the GO mode and the system is ready to resume operational support. The remote computer discrete output equipment can be inhibited, in addition to the manual and countdown intervention, by a malfunction of the discrete input section of both computers or a malfunction in the discrete output logic of the remote computer.

The discrete input error detection logic provides verification on each scan cycle that the discrete equipment correctly processes, both ON and OFF input information, and that the scanning hardware is reset after each scan. Parity bit generation is used to check for errors when transferring the information to the discrete input-output data channel.

The discrete output equipment verifies that the information from the input-output data channel is transferred correctly with no change in the information, by utilizing parity checks and bit shift counters. A check is made to ensure that no more than 24 discretes are issued at one time.

During the hold, the computer personnel have resolved the discrete problem in this manner:

1. The discrete input circuit board is tested by an oscilloscope and found to be defective.

2. After removal of computer power, the circuit board is checked in the module test set located in the computer room.

3. A new board recently tested is installed, power reapplied to the computer, and a validation check performed, including discrete input verification from the discrete input signal conditioning equipment (Figure 4-8).

4. The computer is then reinitialized for support of test operation.

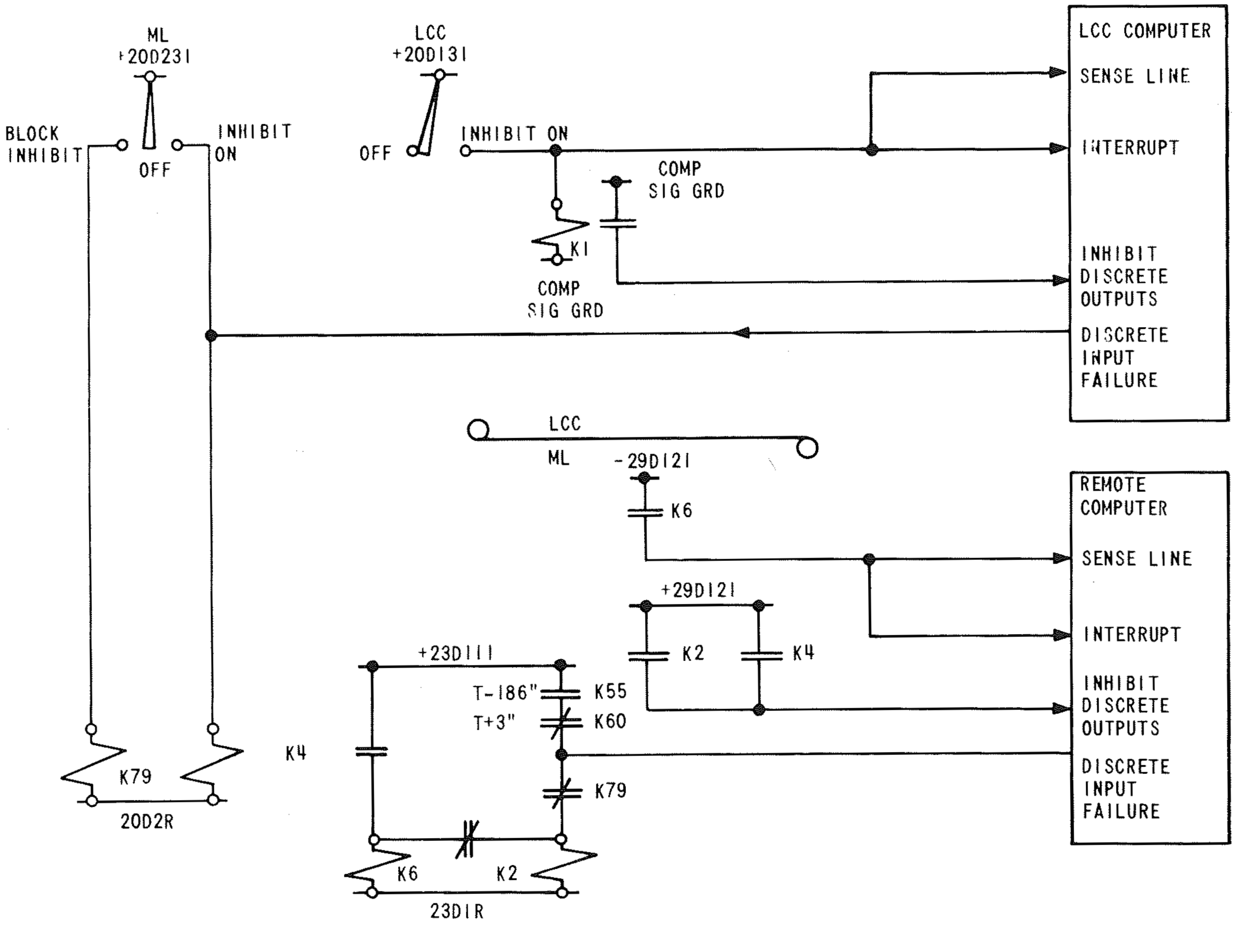

Figure 4-6. Discrete Output Inhibit Control Schematic

METHOD FOR CONTROLLING SIGNALS.	INTERRUPT CAUSES DISCRETE EXEC. PROG. TO DOWN GRADE TO "IDLE" MODE.	SENSE LINE CAUSES DIS-CRETE EXEC. PROG. TO DOWN GRADE TO "IDLE" MODE. AUTO. UPGRADES TO "GO" MODE WHEN RESET.	INHIBITS DISC OUTPUT STROBE (D.O.'S CANNOT CHANGE STATE) MLC IN "IDLE" MODE.
ACTIVATION INHIBIT SW. TO "ON". ML AND/OR LCC	ML AND/OR LCC	ML AND/OR LCC	ML AND/OR LCC
LAUNCH SEQUENCER T-186"	ML ONLY	ML ONLY	ML ONLY
DISCRETE IN ERROR	ML AND/OR LCC	ML AND/OR LCC	ML AND/OR LCC
DISCRETE OUT ERROR (COMP INTERNAL)	NONE	NONE	ML AND/OR LCC
REMOVAL INHIBIT SW TO "OFF" ML AND/OR LCC	ML AND/OR LCC	ML AND/OR LCC	ML AND/OR LCC
INHIBIT SW TO "BLOCK INHIBIT"	ML ONLY	ML ONLY	ML ONLY
LAUNCH SEQUENCER T+3"	ML ONLY	ML ONLY	ML ONLY

Figure 4-7. Discrete Output Inhibit Control Chart

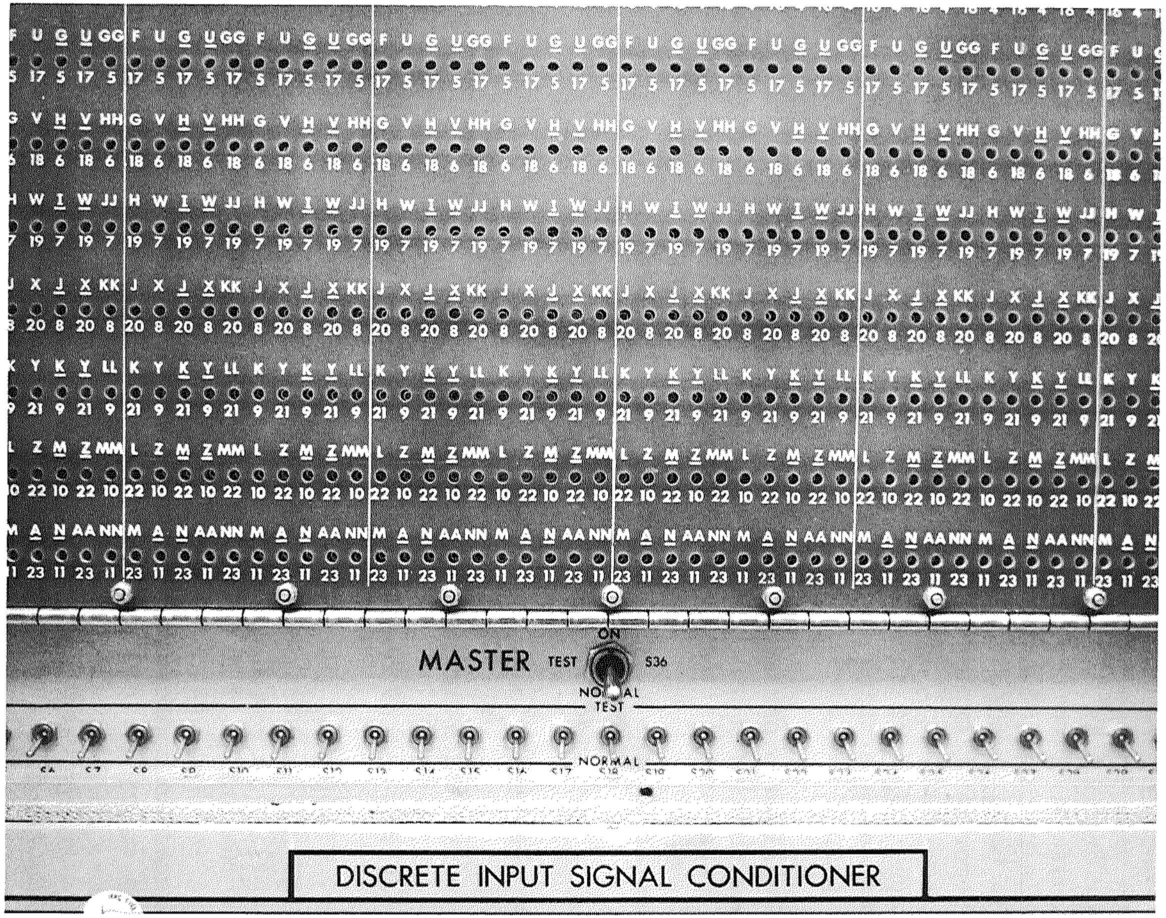

Figure 4-8. Discrete Input Signal Conditioner

C. INDICATION OF MULTIPLE OUTPUT

In the third condition, at T-4 hours, the instrument unit test engineer reports that switch selector functions to the IU stage are resulting in "switch selector output not 2 volts" error messages on the computer line printer. The 2-volt signal is developed in the output section of the switch selector to indicate that only one switch selector is operated with each command. If more than one switch selector channel is ON, the voltage becomes 4 volts, and if no switch selector channel is ON, the voltage is zero. The DDAS receives the signal and transfers it to the computer through the interface unit. The signal is available during the short period of time (40 milliseconds) that the read command is being issued to the switch selector. Therefore, a high-speed oscillograph recorder (Figure 4-9) was patched to receive the DDAS signal in real time for verification. When the switch selector function was repeated, the oscillograph recording showed the output to be two volts, indicating the switch selector was operating normally and the DDAS receiving station was recording the proper signal level.

Suspecting a possible programming problem, a computer memory dump is initiated from the remote control panel and the data investigated by the computer programmer. The data reveals the following normal operations:

1. Computer issues read command.

2. Delay 40 milliseconds.

3. Read DDAS for two-volt signal.

4. If two volts, release read command.

5. If not two volts, output error message and then release read command.

The programmer, finding no programming error, contacts the Saturn Development Facility at MSFC and requests further investigation into the problem. At the development facility, the malfunction is verified and, through experimentation, find that when the delay time to read the DDAS signal is extended to 150 milliseconds, normal results are obtained. With this information, the programmer requests and receives a programming change to patch into the proper computer memory location as an interim solution.

Further studies at the development facility reveal that the time correlation between the computer and the DDAS is in error, resulting in old data being read by the computer. This explained the necessity of the 150-millisecond delay. This is corrected by the DDAS design engineers and subsequently installed in all DDAS systems. The temporary program patch that allowed the 150 millisecond delay is then removed.

Figure 4-9. Oscillograph Recorder

D. SUSPECTED EMERGENCY DETECTION SYSTEM

In the fourth condition, the emergency detection system (Figure 4-10) senses certain launch vehicle performance parameters such as engine thrust and rate of vehicle rotation about the yaw, pitch, and roll axes and sends the information to the command module for automatic or manual cutoff and abort decisions. The emergency detection system circuits contained in the instrument unit consist of majority voting logic; and the system sensors located throughout the launch vehicle stages consist of engine thrust OK pressure switches and emergency detection system rate gyros.

Operational verification of the system is accomplished by a Saturn ground computer complex test program, utilizing a emergency detection system checkout loop (Figure 4-11). The program is initiated and monitored by the test engineer at the computer display console. The computer issues test stimuli, reads vehicle DDAS, and verifies the responses by comparing these responses with predetermined values stored in the computer memory by the test program. Launch vehicle responses are received via hardwire umbilical connections and digital data acquisition, and the spacecraft command module responses via the ACE data link computer interface unit.

At T-2 hours, the emergency detection system test engineer informs the test conductor that a display console message indicates the absence of a rate excessive signal expected through the DDAS. The computer program is automatically halted as a result of this error and provides the test engineer the option of restarting the test at the halted location or initiating a retest. The emergency detection system monitor panel is checked and verification of the malfunction is made by indicator lamps.

A hold is called and the DDAS receiving station operator is contacted. The operator is supplied with the appropriate DDAS address and requested to check its status on the quick-look panel (Figure 4-12). This check reveals that the DDAS discrete in question has not been received. Due to the relative inaccessibility of test points in the vehicle, as compared to the ground support equipment, the trouble isolation is now shifted to the command side of the loop. The test program routine checks the command discrete issuance as well as the response; and since the error message flagged only the response, it is assumed that the command signal cleared the computer interface. Subsequently, voltmeter checks made at the signal conditioner and distributor test points reveal a defective relay. The relay is found to have open contacts when checked in a specially designed relay tester. After a spare is verified and installed, the emergency detection system testing is continued.

E. CUTOFF AFTER TERMINAL COUNTDOWN

The fifth condition is at T-0.2 seconds. During the terminal countdown, an abnormal cutoff signal is received from the circuit logic in the pad area which initiates shutdown of the first stage engines and terminates the countdown. Precautionary signals are automatically generated at cutoff to provide

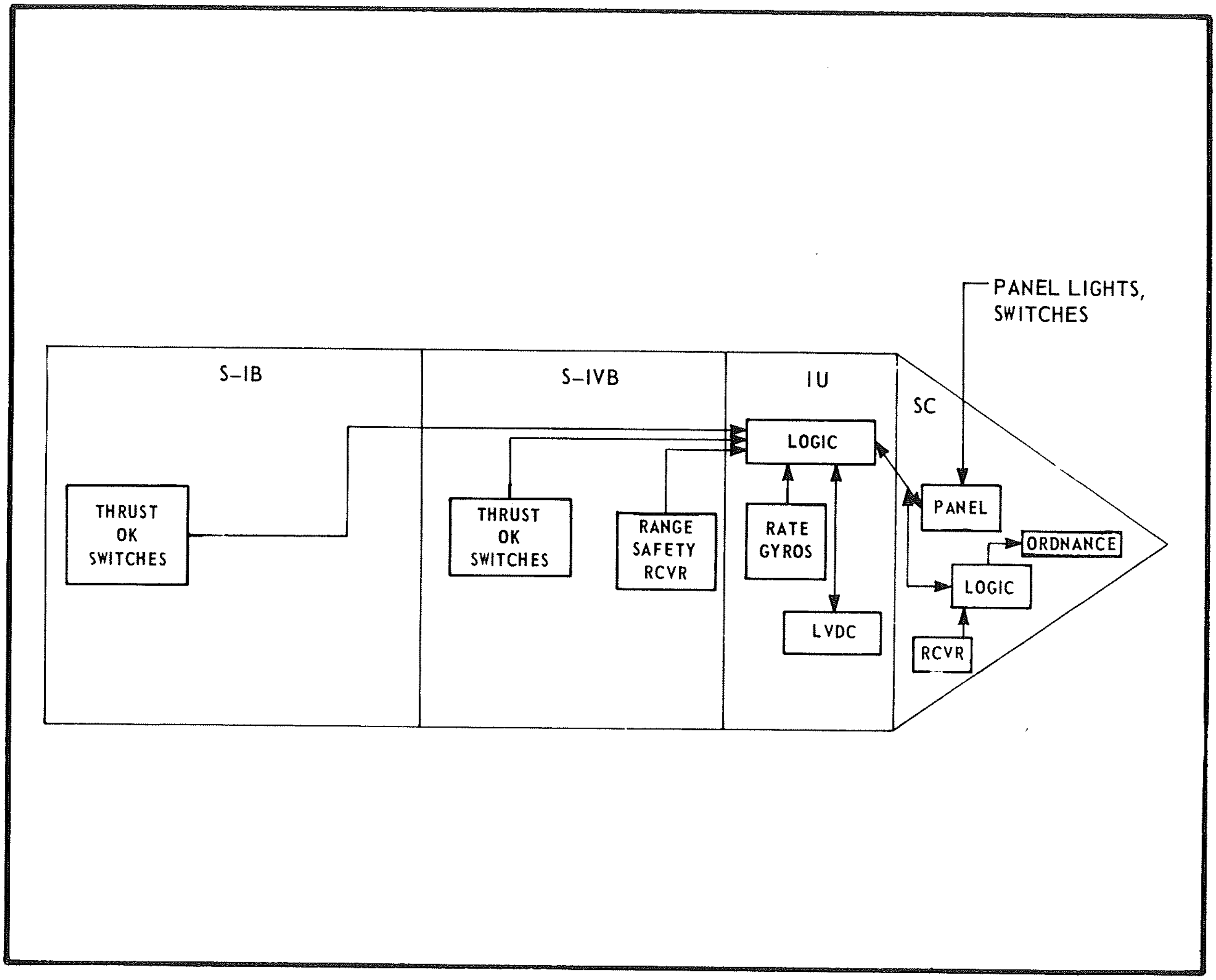

Figure 4-10. Emergency Detection System,
Component Locations

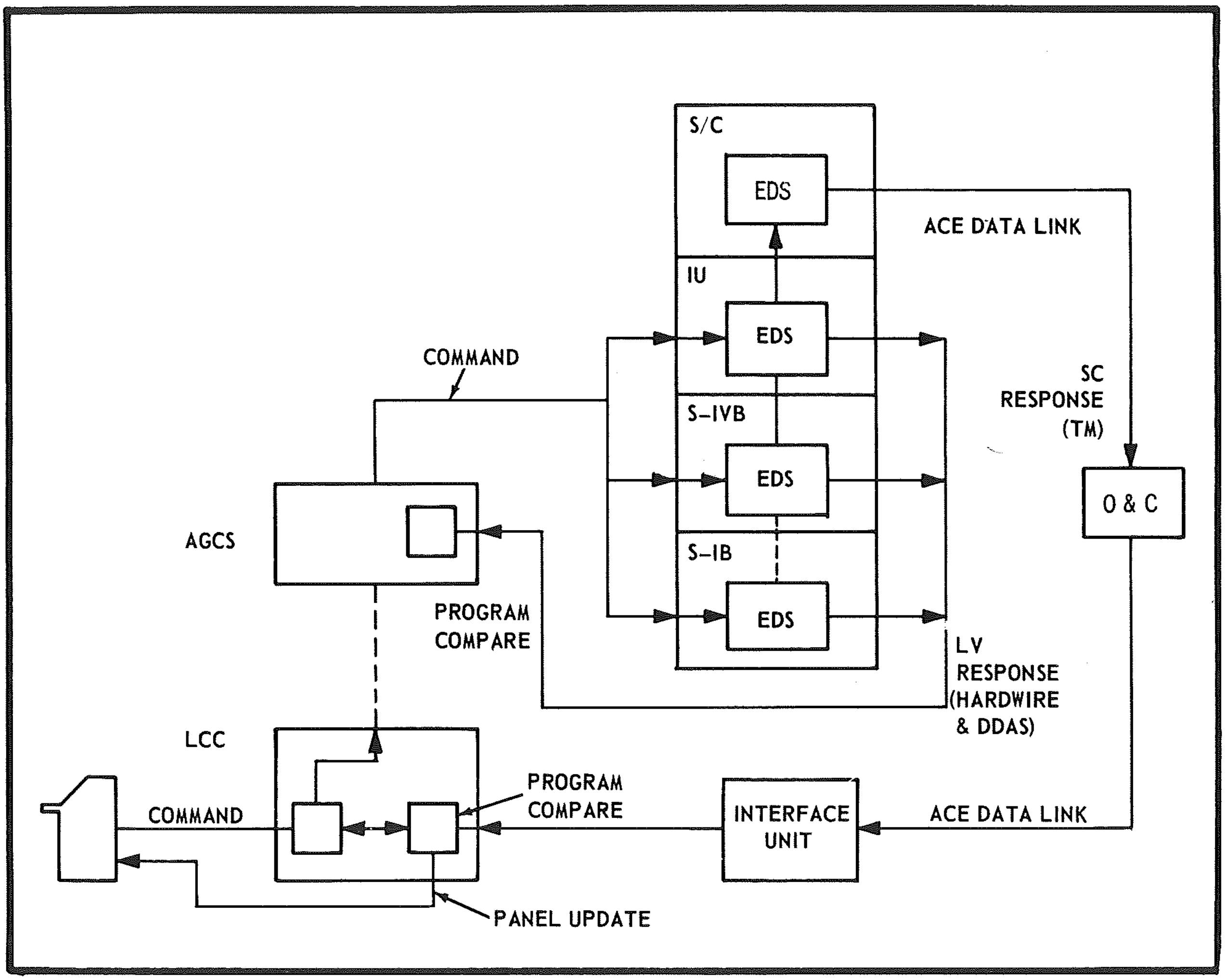

Figure 4-11. Emergency Detection System Checkout Loop

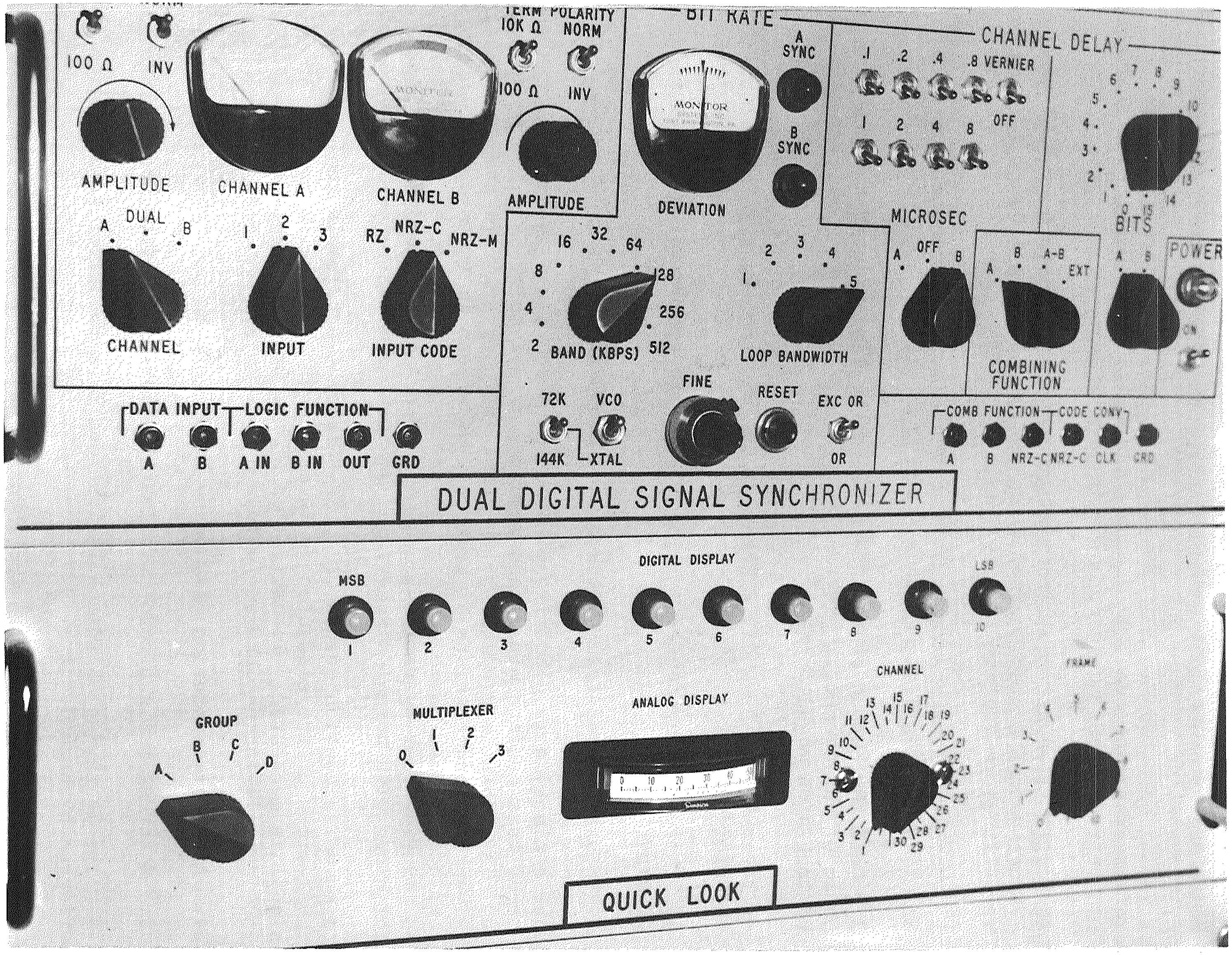

Figure 4-12. Digital Data Acquisition Station Quick-Look Panel

such functions as propellant tank venting, terminal countdown sequencer disarming, transfer of vehicle power to ground supplies, and necessary propulsion system safing operations. Additional manual operations are performed to recycle the system to the T-30 minute configuration and holding, while investigation of the cutoff malfunction is in progress.

The DEE-6 digital events evaluator, which has the capability of real-time data evaluation and system control from the remote control panel (Figure 4-13), will be utilized to isolate this malfunction. DEE-6 capabilities will:

1. Determine the present status of all discretes, a single discrete, or all discretes assigned to a stage printer.

2. Omit the output of any discrete to the line printer and output a table of any discretes previously omitted. Discretes omitted will still be logged on magnetic tape.

3. Select the internal or external timing signals. Select Greenwich or countdown reference time.

4. Select output devices - line printer or typewriter/magnetic tape or paper tape.

5. Start or stop real-time sequence evaluation.

Sequence evaluation is accomplished by comparison of the input discretes as they occur to a predetermined sequence stored in tabular form in the computer memory. The table is prepared by the test engineer prior to the performance of a given test and consists of groups of discretes in the order of their expected occurrence. Each group of discretes may contain one or several discretes. During test operations, sequence errors are flagged on the line printer along with normal discrete information as illustrated in Figure 4-14.

When a cutoff situation occurs, the DEE-6 becomes a valuable tool for real-time evaluation of the situation as it exists at the precise moment the cutoff signal is generated. Investigation of the DEE-6 line printer reveals sequence compare indications as follows:

1. A cutoff indication flagged by error code 3.

2. A thrust failure cutoff indication flagged by error code 3.

3. The 24 thrust OK switch indications from the first stage engine flagged by error code 4.

During test operations, the engine thrust OK pressure switches are simulated in the overall test room (Figure 4-15). The simulators can be operated individually by test switches or all 24 switches by a time-delayed signal derived from the last output of the ignition sequencer. The latter means is used

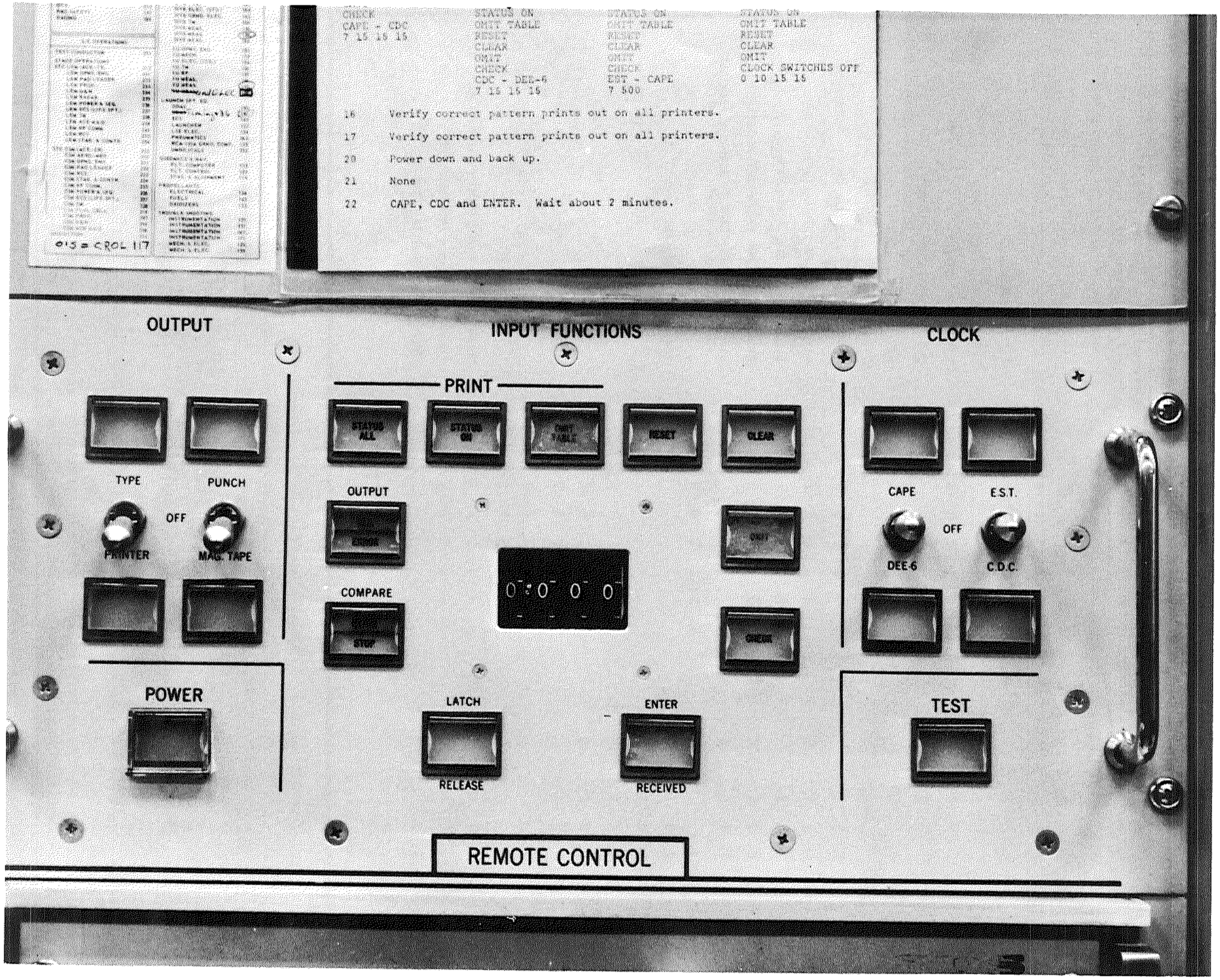

Figure 4-13. Remote Control Panel

							TIME COUNT													
SPECIAL CODE		RESOLUTION					HRS.	HRS.		MIN.	MIN.		SEC.	SEC.		M.SEC	M. SEC	M. SEC.	C/R	
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	
0							2	3		5	8		5	9	.	9	9	9		E.S.T. TIME CHANGE
0							2	3		5	9									E.S.T. MINUTE INDICATION
1						–	0	1		2	3		1	9	.	0	0	0		C.D.T. TIME CHANGE
1						–	0	1		2	2									C.D.T. MINUTE INDICATION
				DISCRETE					OFF	ON										
				0	0	9	6			1			5	8	.	0	6	6		DISCRETE 0096 ON AT TIME -01:21:58:066 (CDT)
	0	2		0	3	2	5		0				4	3	.	0	6	7		DISCRETE 325 OFF WITH EFFECTIVE 2 MSEC SCAN RESOLUTION
2				1	2	4	9			1			3	4	.	7	0	1		DISCRETE 1249 OUT-OF-SEQUENCE
3				2	0	0	6		0				2	5	.	2	8	0		DISCRETE 2006 NOT IN COMPARISON TABLE
4				3	9	8	0		0											DISCRETE 3980 EXPECTED TO OCCUR IN PREVIOUS GROUP BUT DID NOT OCCUR
5													2	3	.	5	8	0		
5				0	0	0	1		0											DEMAND PRINTOUT (ALL)
5				0	0	0	2			1										
5				2	0	1	6		0											
6				0	0	0	4		0				2	2	.	6	8	0		OMIT TABLE
				0	0	0	4			1			2	2	.	6	8	0		
7													2	2	.	7	0	0		POWER FAIL
0						–	0	1		2	2		2	2	.	5	0	0		
9	I	I	I	I	I	I	I	I	I	I	I		1	4	.	0	0	1		CHANGE BUFFER FULL, SCANNING TERMINATED
8	–	–	–	–	–	–	–	–	–	–	–		2	1	.	8	9	6		CHANGE BUFFER NON-FULL CONDITION
–	1	–		0	7	3			1											SWITCH SELECTOR OCTAL CODE

Figure 4-14. DEE-6 Line Printer Format

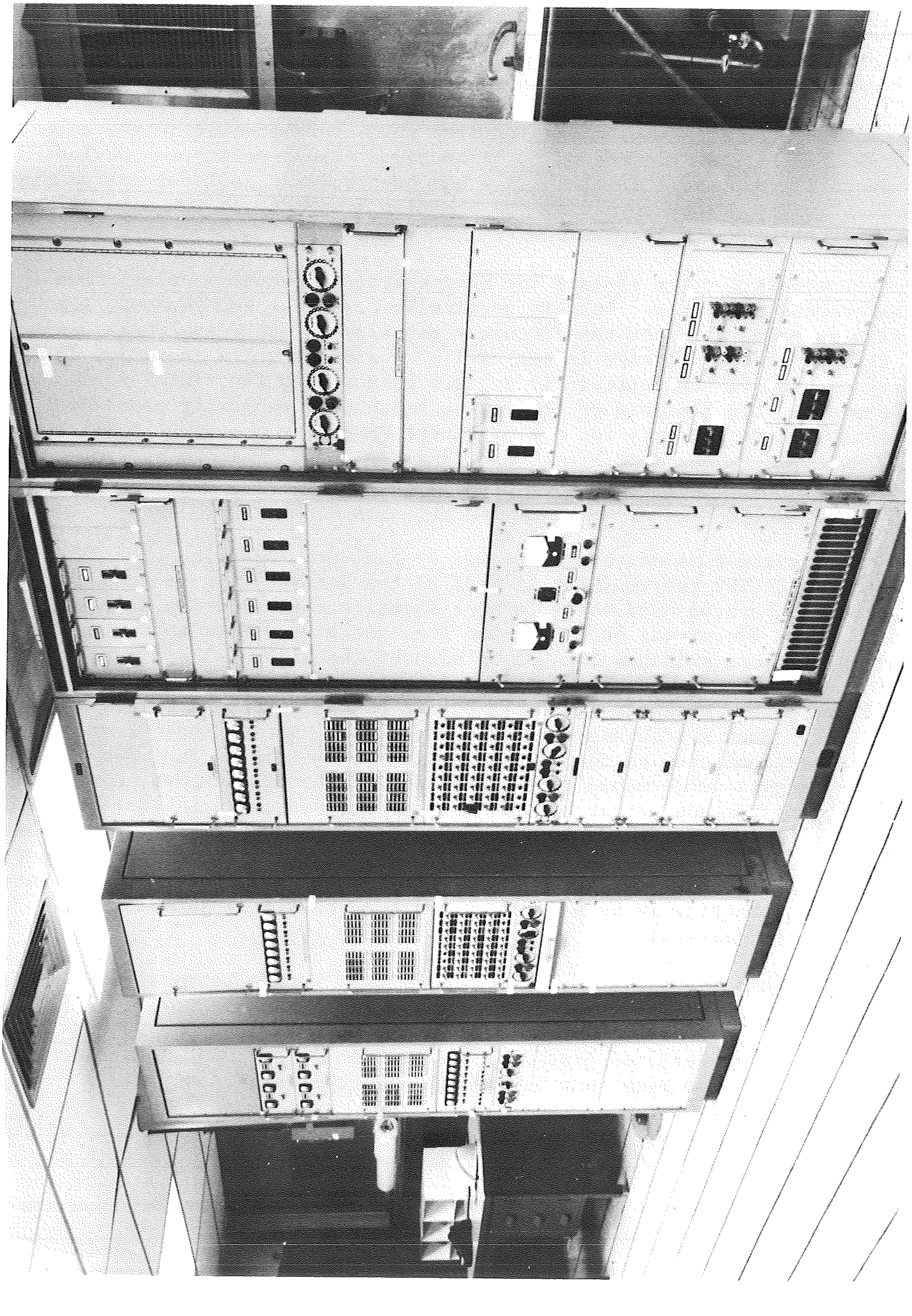

Figure 4-15. Overall Test Room

during the terminal countdown of test operations. The overall test room technician verifies proper operation of the simulator circuits from the test panel switches. Also, the ignition sequencer output signals are indirectly verified on the events chart in the sequence recorder (Figure 4-16) by observing the feedbacks from the engine ignition initiators mounted in the test chambers. With this information gathered from various monitoring devices throughout the system, the malfunction has been quickly isolated to the distribution system of the output of the ignition sequencer in the simulation circuitry in the overall test room.

Voltmeter checks further isolate the malfunction to the time delay circuit in the overall test room. In this particular case, for two reasons, the decision is made to jumper the circuitry manually as shown in Figure 4-17; (1) the malfunction circuit is not easily repairable while installed in the system; and (2) the circuit is in test rather than functional portions of the system. The technician closes the switch on the jumper panel manually to provide the test signal for engine thrust OK at the proper time in the countdown.

F. CALIBRATABLE PRESSURE SWITCH SYSTEM (CALIPS)

The sixth condition is not a problem but is included to explain the CALIPS system. The CALIPS system (Figure 4-18) of the Saturn IB first stage is a pneumatic system used to perform calibration checks during prelaunch operations and functional checks during the launch countdown to verify the thrust OK pressure switches located on each of the eight H-1 engines. The CALIPS console provides a calibrated pressure ramp through two separate orifices leading to a manifold for distribution to the 24 CALIPS switches in the vehicle. Each switch has two input ports; one receiving the test pressure and the other connected to the discharge line of the engine fuel pump for monitoring engine performance after ignition. Either input port, operating through a diaphram and actuator, will actuate a feedback switch for indication at the LCC. In the CALIPS console a transducer senses the manifold pressure and an analog-to-digital-converter sends the digital information to the pad area computer. The CALIPS equipment is operated manually from the LCC control console, or automatically by a computer test program. The automatic test is performed as follows:

1. The computer operates valves in the CALIPS console to start a course pressure ramp and checks the ramp tolerance.

2. At a predetermined pressure, course ramp is stopped and a fine ramp is started. The fine ramp is also tolerance checked.

3. CALIPS switches are monitored and actuation pressure data is stored in memory.

4. When all 24 switches actuate, or a predetermined maximum pressure is reached, the manifold is slowly vented.

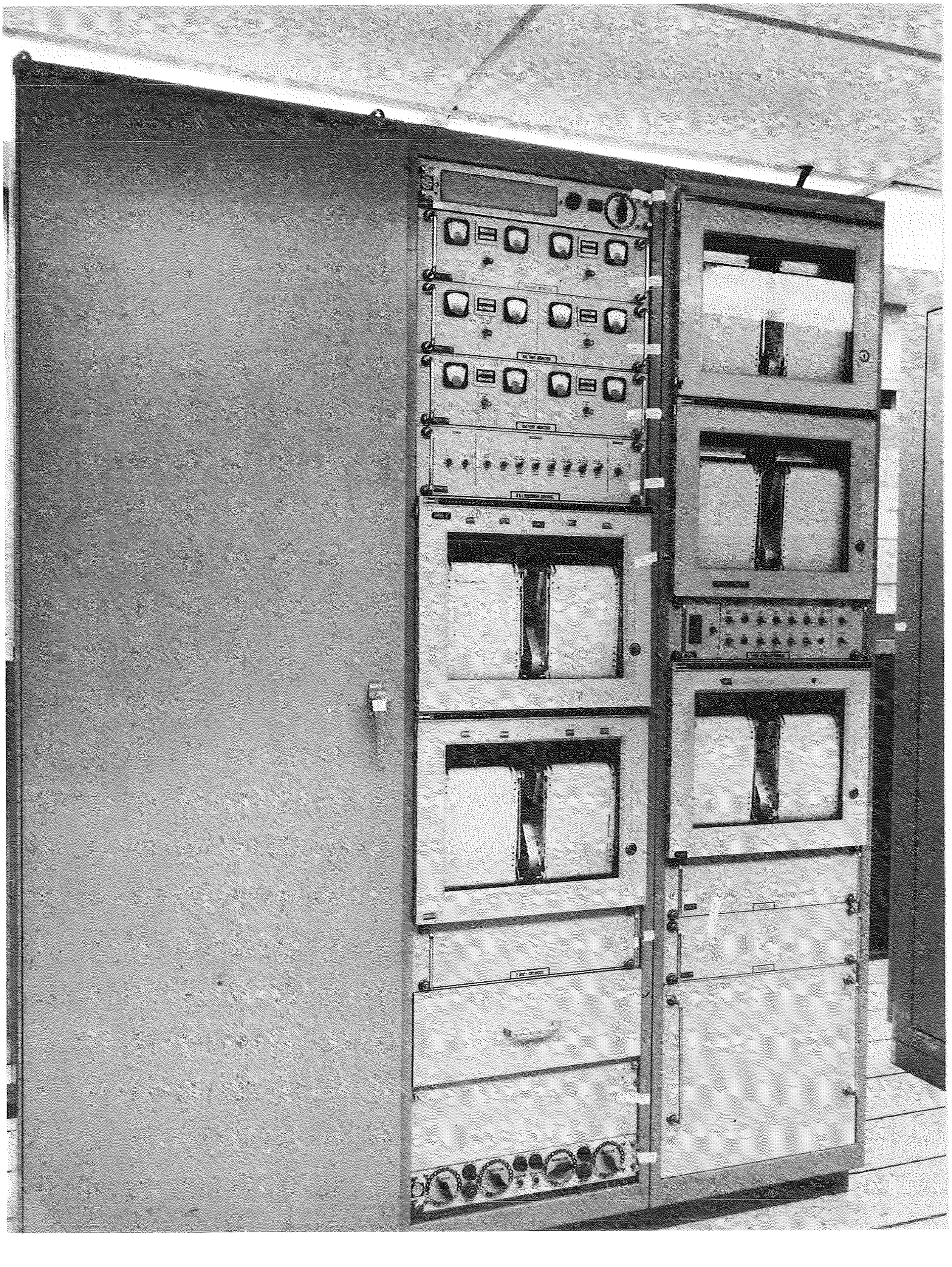

Figure 4-16. Overall Test Sequence Recorders

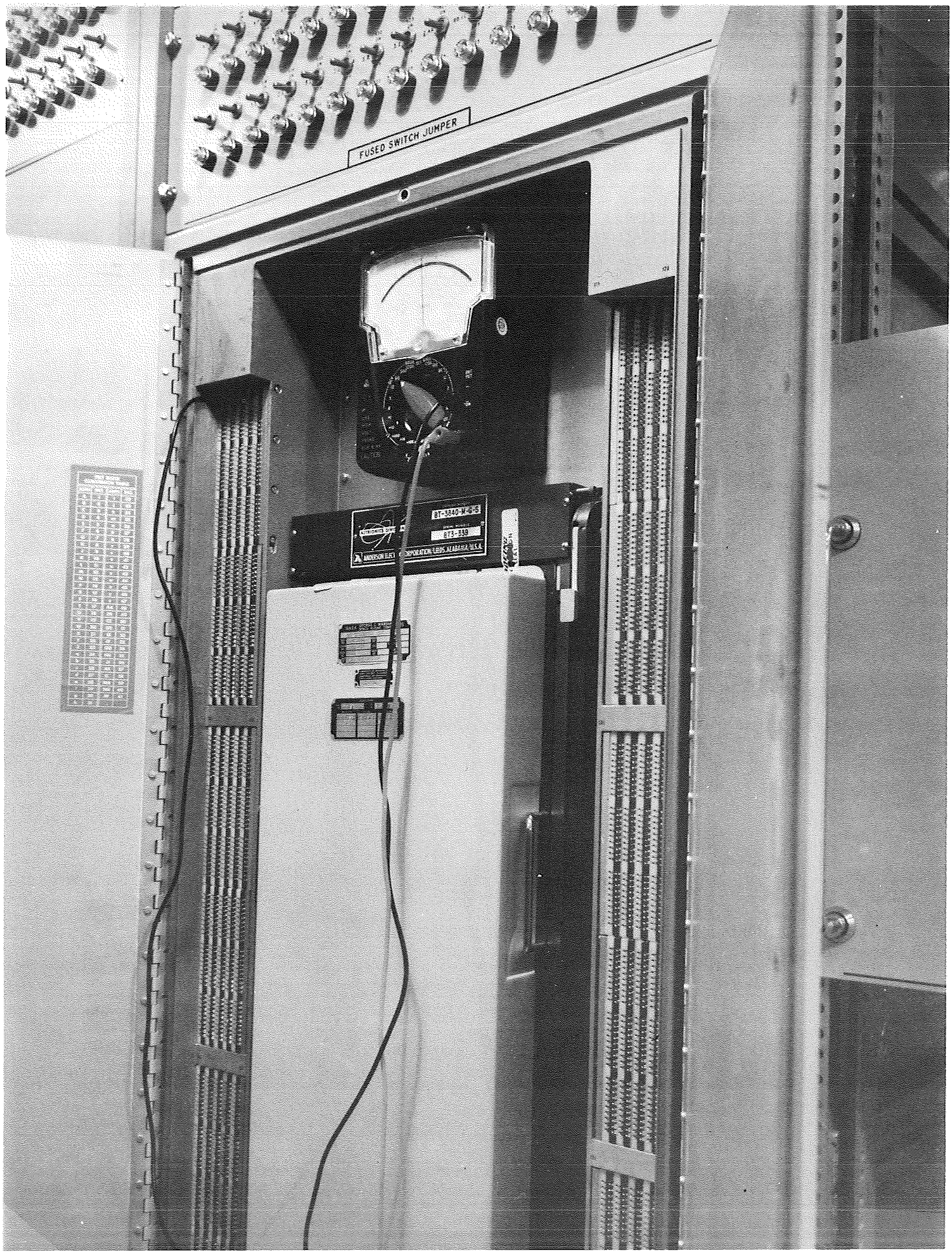

Figure 4-17. Programmable Patch Distributor

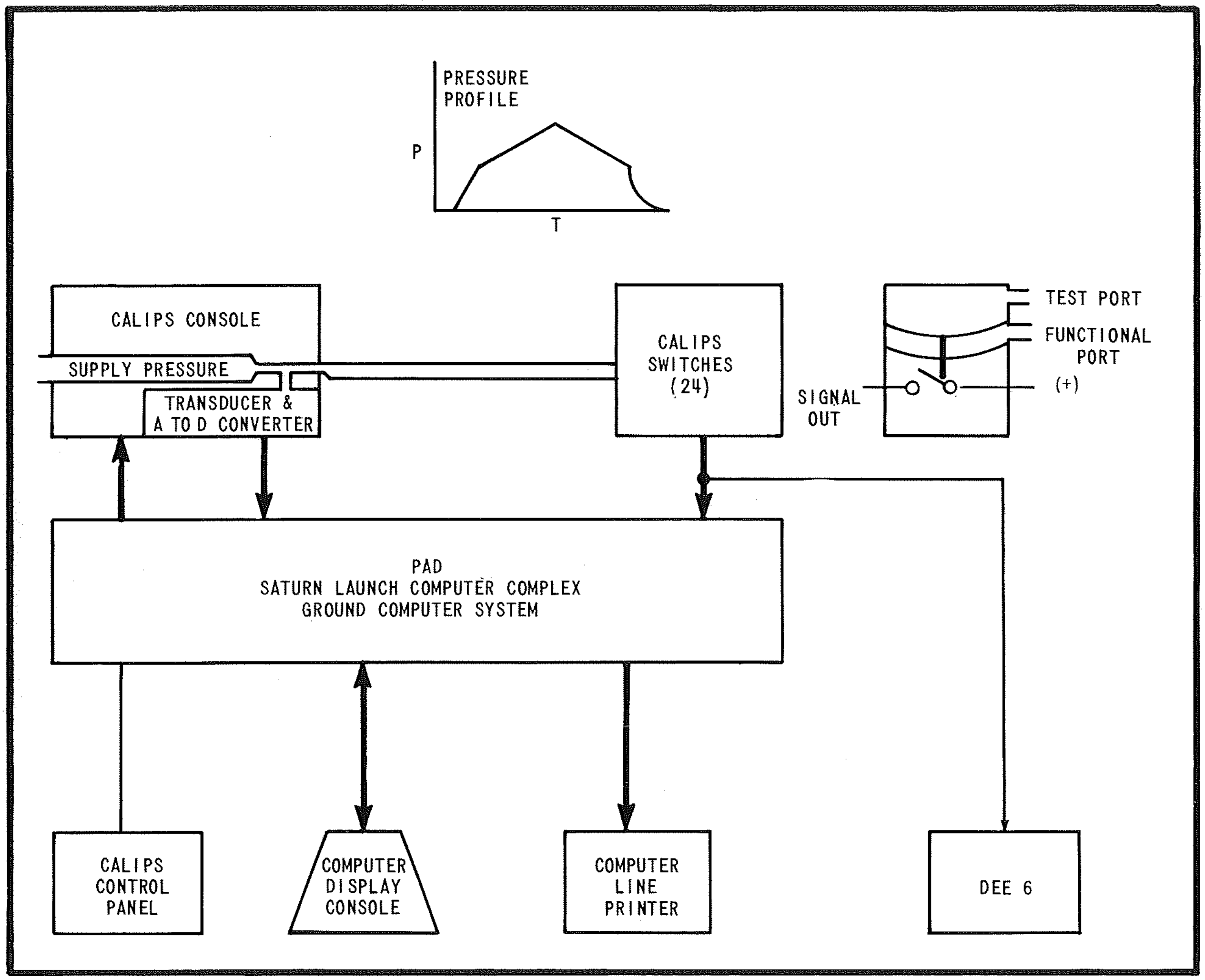

Figure 4-18. CALIPS System Program Functional Diagram

5. CALIPS switches are monitored during venting and deactuation pressure data is stored in memory.

6. When all CALIPS switches deactuate, the pressure is vented at a more rapid rate to zero and the computer will output the test data.

Throughout the entire operation, at 15-second intervals, the computer displays the manifold pressure on the display console and line printer for observation by the test engineer. The output data, at completion of the program, is read on the computer line printer. The output format (Figure 4-19) includes the switch specifications, the actuation and deactuation pressure of each switch, and the rate of pressure change during the course and fine ramps.

CALIPS PROGRAM DATA OUTPUT

TOPS MAKE PRESSURE LOW LIMIT 755 PSIG
UP LIMIT 815 PSIG
TOPS BREAK PRESS 20 PSI TO 45 PSI LESS THAN MAKE PRESSURE

ENG SWH	ACT PRES	DEA PRES	DELTA P
EN1- 1	790.699	762.560	28.139
1- 2	764.330	738.877	25.453
1- 3	788.440	754.503	33.938
EN2- 1	773.791	746.934	26.857
2- 2	779.651	754.259	25.392
2- 3	779.651	750.657	28.994
EN3- 1	792.652	757.188	35.464
3- 2	803.395	778.491	24.904
3- 3	768.236	743.821	24.416
EN4- 1	791.370	763.353	28.017
4- 2	772.143	742.844	29.299
4- 3	799.977	775.073	24.904
EN5- 1	791.370	762.804	28.566
5- 2	799.488	775.500	23.988
5- 3	786.487	752.549	33.938
EN6- 1	782.581	754.075	28.505
6- 2	792.652	770.617	22.035
6- 3	772.326	742.844	29.482
EN7- 1	775.500	749.375	26.125
7- 2	763.353	732.101	31.252
7- 3	759.142	732.101	27.040
EN8- 1	773.120	738.633	34.487
8- 2	781.909	751.634	30.275
8- 3	766.955	741.562	25.392
TRANSDUCER READING		3.131 PSI	

IN TOLERANCE

COARSE RAMP PRESSURE IN TOLERANCE
PRESSURE CHANGE FOR 1 MINUTE EQUALS 203.138 PSI

FINE RAMP PRESSURE IN TOLERANCE
PRESSURE CHANGE FOR 1 MINUTE EQUALS 17.396 PSI

NT14 COMPLETE-EXIT TO OPERATING SYSTEM
GMT 2043/35.260
CALIPS MANIFOLD PRESSURE ∘ 479.156
GMT 2043/50.788
CALIPS MANIFOLD PRESSURE ∘ 458.342

Figure 4-19. CALIPS Program Data Output

SECTION V
CONCLUSIONS

At the present time, Kennedy Space Center is engaged in all of the Saturn/Apollo checkout activities that have been discussed. Launch vehicle checkout activities involving four manned Saturn/Apollo launch vehicles are in various phases of preparation. At Launch Complex 34, stage checkout of a Saturn IB vehicle (designated AS-205) has been completed, and launch vehicle checkout is now in progress. To date, a total of 90 defined test programs have been released for checkout operations; this includes consolidation of 38 control system programs into 8 programs. At Launch Complex 39, firing room number 1 and mobile launcher number 1 will be used for checkout of a Saturn V/Apollo vehicle designated AS-503. Erection of this vehicle is nearing completion. Launch Pad A will be used for the launch. Firing room number 2 and mobile launcher number 2 are being prepared to receive Saturn V/Apollo vehicle AS-504, which will be launched from Pad B. Firing room number 3 and mobile launcher number 3 are in process of validating all control and checkout equipment (GETS checkout) for AS-505, which will be launched from Pad A. Of the test programs defined, 80 have been released for use on AS-503 and 65 for use on both AS-504 and AS-505. Also, preliminary planning is under way for the Apollo Applications Program which will utilize the existing launch facilities including the associated control and checkout systems.

Launch activities on this scale present problems, regardless of how well planned. However, these problems are the type that can be revealed by operational utilization of all of the features built into the space vehicle control and checkout system. Namely:

1. Continuous monitoring of visual displays by all operational personnel at the launch site.

2. Built-in self checks of equipment and real-time analysis performed by computer programs.

3. Utilization of all available test points for fault isolation and alternate modes of equipment operation.

There are, however, a few problems that are troublesome and are causing additional time and effort during vehicle checkout and launch operations.

To increase reliability and the ability to meet critical time schedules, the designers have provided redundancy. To determine that all alternate modes were functioning properly, additional testing had to be employed. In many instances, use of automatic checkout equipment and computer test programs have been provided to decrease the time required for checkout. However, some equipment does not contain this feature. This problem is being remedied within the time and resource constraints imposed upon launch operations.

There are divided opinions as to the best type of grounding system to use; single point or multipoint. Launch vehicle operations uses the single point grounding system. The usual problem related to the combination of the two grounding systems are the numerous ground loops which require time to isolate and eliminate.

Sensors and indicators do not always have the same reliability as the devices they are monitoring. When a malfunction is detected, time is required to determine what has failed, the device or the sensor. If the sensor was the cause of the malfunction, this sometimes necessitates the use of temporary by-passes around the sensor circuitry to facilitate uninterrupted testing. In addition to this problem, there is usually no forewarning that the device is about to fail. Sensors or indicators are needed that provide intelligence information as to the condition of the device. This information would then provide the test engineer with trend information on the device so that it could be replaced before it fails.

Built-in, self-check features provide indicators, alarms, or displays whenever nonnominal conditions occur. This allows the system test engineers more time to perform their additional tasks. Occasionally, the information provided is too gross and time is required to determine and isolate the cause of the malfunction, especially if the malfunction is intermittent.

It was recognized early in the design phases of the vehicle control and checkout systems, which contain a number of digital computers, that there would be a communication problem with the programmers. This led to development of a method for generating computer test programs using a language oriented toward the test engineer. This enables the test engineer to understand all required documentation and to prepare automatic test programs to perform the required test procedures. The acceptance test or launch language (ATOLL) has lessened the communication problem and has significantly reduced test preparation and debugging time. However, since many programs still must be prepared using a language oriented toward the computer programmer, the communication problem still exists.

Excessive use of the display control consoles to call up the execution of normal and predetermined options of test programs requires additional operational time. This problem has been recognized, and an additional ATOLL feature designed to alleviate this situation will soon be released for AS-503 or AS-504. This feature will provide the ability to select any given number of test programs, including any options within the test programs designed for automatic sequencing. Plans are presently being considered using this feature to automate the final 30 minutes of each major overall test and countdown.

Future development of control and checkout systems depends on the designers who consider the operational requirements furnished by the system test engineers. Operational requirements, including those already established, that should be considered for future development of control and checkout systems are as follows:

1. Retention of manual intervention and control when optimization of the manual portion of the control and checkout system is being considered.

2. Provisions for detailed automatic fault analysis or indicators in addition to the gross malfunction indicators already established.

3. Provisions for automatic recorders that continuously monitor the system, but operate only when a malfunction is detected; the recorders must contain enough memory capacity to allow the equipment to reach operating speed and to record the malfunction. This recording equipment must be able to stop automatically after a predetermined interval of time, or when the malfunction no longer exists.

This concludes the discussion of the Saturn/Apollo space vehicle control and checkout system and the importance of the role this system is playing in aiding our efforts to successfully complete the Saturn/Apollo program.

APPENDIX A
LIST OF ABBREVIATIONS

ACE	–	Acceptance Checkout Equipment
ATOLL	–	Acceptance Test or Launch Language
BH	–	Block House
CALIPS	–	Calibratable Pressure Switch System
CDC	–	Countdown Clock
CIF	–	Central Instrumentation Facility
CRT	–	Cathode Ray Tube
CT	–	Crawler Transporter
DDAS	–	Digital Data Acquisition System
DEE-6	–	Digital Event Evaluator
EDS	–	Emergency Detection System
ESE	–	Electrical Support Equipment
FM	–	Frequency Modulation
GETS	–	Ground Equipment Test Set
GLOTRAC	–	Global Tracking
GMT	–	Greenwich Mean Time
GSE	–	Ground Support Equipment
IU	–	Instrument Unit
LC	–	Launch Complex
LCC	–	Launch Control Center
LDI	–	Launch Control Center Discrete Input
LDO	–	Launch Control Center Discrete Output
LIEF	–	Launch Information Exchange Facility
LUT	–	Launch Umbilical Tower
LVDC/LVDA	–	Launch Vehicle Digital Computer/Launch Vehicle Data Adapter
MDI	–	Mobile Launcher Discrete Input
MDO	–	Mobile Launcher Discrete Output
ML	–	Mobile Launcher
MSC	–	Manned Spacecraft Center
MSFC	–	Marshall Space Flight Center
MSS	–	Mobile Service Structure
O&C	–	Operation and Checkout Building
OAT	–	Overall Test
ODOP	–	Offset Doppler
PAM	–	Pulse Amplitude Modulation
PCM	–	Pulse Code Modulation
PDM	–	Pulse Duration Modulation
PTCS	–	Propellant Tanking Computer System
PTCR	–	Pad Terminal Connection Room
RACS	–	Remote Automatic Calibration System
RF	–	Radio Frequency
SDF	–	Saturn Development Facility
SGCC	–	Saturn Ground Computer Complex*
UHF	–	Ultra High Frequency
VAB	–	Vehicle Assembly Building
VHF	–	Very High Frequency

* Sometimes referred to as SLCC – Saturn Launch Computer Complex

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